Environment
Canada

Environnement
Canada

Canada - Ontario Agreement on Great Lakes Water Quality

Ministry
of the
Environment

Ontario

# Impact of Nitrilotriacetic Acid (NTA)

# on an Activated Sludge Plant

# Research Report No. 91

**Research Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality**

CANADA-ONTARIO AGREEMENT

RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations
funded under the Research Program for the Abatement of Municipal Pollution
within the provisions of the Canada-Ontario Agreement on Great Lakes Water
Quality. They provide a central source of information on the studies
carried out in this program through in-house projects by both Environment
Canada and the Ontario Ministry of Environment, and contracts with
municipalities, research institutions and industrial organizations.

Enquiries pertaining to the Canada-Ontario Agreement RESEARCH
PROGRAM should be directed to -

> Wastewater Technology Centre
> Canada Centre for Inland Waters
> Environment Canada
> P.O. Box 5050
> Burlington, Ontario   L7R 4A6
>
> Ontario Ministry of Environment
> Pollution Control Branch
> 135 St. Clair Avenue West
> Toronto, Ontario   M4V 1P5

IMPACT OF NITRILOTRIACETIC ACID (NTA) ON AN

ACTIVATED SLUDGE PLANT - A FIELD STUDY

by

N. Wei, R. Stickney, P. Crescuolo and B.P. LeClair
Wastewater Technology Centre
Environmental Protection Service
ENVIRONMENT CANADA

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION UNDER THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

Project No. 71-3-3

This document may be obtained from -

Training and Technology Transfer
   Division (Water)
Environmental Protection Service
Environment Canada
OTTAWA, Ontario
KIA 1C8

Ontario Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue West
TORONTO, Ontario
M4V 1P5

# ABSTRACT

A field study on the effects of nitrilotriacetic acid (NTA) on activated sludge was carried out at the Waterdown Water Pollution Control Plant, from January, 1972 to April, 1973. The Waterdown Plant is a conventional activated sludge plant with a design flow of 1 362 $m^3$/d. The nominal wastewater flow was approximately 45% of design capacity and all homes served by the sewer system were within a mile and a half of the treatment plant.

The areas investigated in the study include: degradation of NTA, effect of NTA loading on chemical treatment for phosphorus removal, NTA loading and heavy metal removal in the treatment plant, and effect of NTA loading on treatment plant operation.

The NTA was added to the treatment plant in the form of Sunlight Soap (a commercial laundry detergent containing 20 wt % NTA) at two rates to approximate NTA spiking levels of 8 mg/L NTA and 16 mg/L NTA. The background NTA loading in the raw wastewater averaged 2.5 mg/L NTA. Diurnal variation studies of the NTA loading showed peak values of 12 mg/L NTA in the afternoon and minimum values of 0.1 mg/L NTA at night. The raw wastewater had an average $BOD_5$ of 100 mg/L, a suspended solids of 150 mg/L, and a total phosphorus loading of 6.0 mg/L P. Heavy metal levels averaged 0.2 to 0.5 mg/L for zinc, aluminum and iron, and 0.01 to 0.1 mg/L for lead, nickel and copper. The treatment plant efficiency averaged 86% $BOD_5$ and 85% suspended solids removal throughout the study.

Such factors as microorganism acclimatization to NTA, chemical addition for P removal, temperature and NTA loading, were analyzed by grouping the field data in such a manner that the sole effect of each factor could be analyzed with all other factors held constant. The studies demonstrated that NTA loadings up to 16 mg/L NTA did not adversely affect treatment plant efficiency or the amount of chemical precipitant required to meet an effluent total phosphorus objective of 1 mg/L P. NTA degradation was significantly affected by wastewater temperature. Correlation of heavy metal transport through the treatment plant with NTA loading was inconclusive.

i

## RÉSUMÉ

Les effets de l'acide nitrilotriacétique (NTA) sur les boues
activées ont fait l'objet d'une étude expérimentale, de janvier 1972 à
avril 1973, à l'usine d'épuration de Waterdown. Il s'agit d'une installation
classique aux boues activées, d'une capacité de 1362 $m^3$/j. Cette capacité
n'est exploitée qu'à 45% environ. Toutes les habitations desservies par
le réseau d'égout sont situées dans un rayon d'un mille et demi de l'usine.

Les points étudiés ont été la dégradation du NTA, les effets de
sa charge sur la déphosphatation, sur l'élimination des métaux lourds et
sur le rendement de l'épuration.

Du savon Sunlight, qui contient en poids 20% de NTA, a été ajouté
en quantité suffisante pour que la teneur en NTA atteigne 8 et 16 mg/L.
Avant ces additions, la concentration de NTA dans les eaux brutes était de
2.5 mg/L. D'après les études de la variation, sur 24 heures de la charge
de NTA, sa concentration maximale (12 mg/L) a été atteinte l'après-midi,
tandis qu'elle était à son minimum (1 mg/L) la nuit. En moyenne, les eaux
brutes avaient une $DBO_5$ de 100 mg/L, 150 mg de matières en suspension/L
et 6.0 mg P/L. Leur teneur en zinc, en aluminium et en fer variait entre
0.2 et 0.5 mg/L, celle du plomb, du nickel et du cuivre, entre 0.01 et 0.1
mg/L. Au cours de l'étude, la $DBO_5$ a été réduite de 86% en moyenne, et 85%
des matières en suspension ont été éliminées.

L'analyse de l'adaptation des micro-organismes au NTA, de l'addition
de réactifs pour la déphosphatation, de la température et de la charge de
NTA s'est faite à partir de données expérimentales que avaient été regroupées
de telle façon qu'on puisse faire varier un seul facteur à la fois, les
autres demeurant constants. Les recherches ont montré que des charges de
NTA aussi élevées que 16 mg/L n'ont pas nui à l'épuration ni nécessité
davantage de réactifs chimiques pour atteindre l'objectif de 1 mg de P/L
dans l'effluent. La température des eaux résiduaires a influé sensiblement
sur la dégradation du NTA. Aucune corrélation n'a pu être établie entre
la circulation de métaux lourds et la charge de NTA.

TABLE OF CONTENTS

## TABLE OF CONTENTS (CONT'D)

# LIST OF FIGURES

# CONCLUSIONS AND RECOMMENDATIONS

## CONCLUSIONS

A field study on the effects of nitrilotriacetic acid (NTA) was carried out at the Waterdown Water Pollution Control Plant from January, 1972 to April, 1973. The areas investigated in the study included: NTA degradation, the effect of NTA loading on chemical treatment for phosphorus removal, and NTA loading and heavy metal removal. The studies demonstrated the following:

1. NTA loadings up to 16 mg/L NTA did not adversely affect the amount of chemical precipitant required to meet an effluent total phosphorus standard of 1 mg/L P. Chemical treatment processes included both alum addition to the aeration tank, and ferric chloride and polymer addition to raw sewage.

2. NTA loadings up to 16 mg/L NTA did not adversely effect the treatment plant efficiency or cause any operating problems.

3. The microbial population in the aeration tank required approximately two to three weeks to acclimatize to each of the higher NTA loadings.

4. NTA degradation in the treatment plant was significantly affected by wastewater temperature. With background NTA levels of 3 mg/L NTA or less, the degradation rate was relatively independent of wastewater temperature. With high NTA loadings (NTA levels greater than 8 mg/L NTA) the removal rate was strongly correlated with wastewater temperature. The NTA removal rate also decreased with increased NTA loading.

5. The correlation of heavy metal transport through the treatment plant with NTA loading was inconclusive. Zinc and iron removals in the treatment plant decreased with increasing NTA concentration in the effluent while copper, aluminum, nickel and lead showed no correlation.

RECOMMENDATIONS

The following specific areas for further investigation are recommended:

1.      A detailed study of the removal of NTA from a large sewage treatment plant [45 400 m³/d (10 MIGD)] should be undertaken. The performance during low temperature winter conditions should receive close scrutiny. The plant chosen should also have a relatively high metals input so that metal transport may also be monitored.

2.      More fundamental studies at pilot plant level where close control can be maintained are required to evaluate the effects of temperature, NTA loading and NTA shock loading on NTA removal by the activated sludge process. Controlled experiments into the effect of NTA loading on metal transport are also necessary to elucidate the metal transport mechanism.

1       INTRODUCTION

In August, 1971, the government of Canada and the government
of the province of Ontario signed an agreement to ensure that the water
quality of the Great Lakes is restored and protected. This
"Canada-Ontario Agreement on Great Lakes Water Quality" was signed in
response to the recommendations of the International Joint Commission
(IJC) concerning pollution of the Lower Great Lakes and in anticipation
of the Canada-United States Agreement on Great Lakes Water Quality.
The purpose of this Canada-Ontario Agreement was to permit Canada and
Ontario to effectively carry out their obligations under the Inter-
national Agreement. An additional important provision of the Agreement
was for the conduct of a research program for reducing costs of
programs to achieve the specific water quality objectives set out in
the Agreement. Thus, late in 1971, research programs were initiated on
chemical removal methods, sludge handling, sludge disposal and other
matters related to the process of removal of nutrients such as phosphorus
from sewage.

In May, 1972, the Federal Environment Minister announced new
regulations, effective January, 1973, further restricting the phosphorus
content of detergents to 5% $P_2O_5$. At the same time, the Minister also
announced that the levels of substitute builders would be monitored to
safeguard the environment. One such substitute builder is nitrilo-
triacetic acid (NTA) which has been used in some synthetic detergents
as a substitute for polyphosphates which are considered to be a
major cause of lake eutrophication. However, questions have been
raised as to the possible environmental effects that could result from
a large scale usage of NTA in detergents.

As a result, many laboratory studies have been conducted on
the biodegradability of NTA and its metal complexes (Shannon et al,
1978) and their toxicity to marine life. Most of these studies are
summarized in the comprehensive literature reviews of Thom (1971),
Epstein (1972), Thayer and Kensler (1973) and Prakash (1976). There

was also a full scale field study on NTA removal by the activated sludge process (Shumate et al, 1970). During the winter of 1971, a full scale field study on the effect of NTA detergent on a biological treatment plant was carried out by the Environmental Protection Service at the Canadian Forces Station Gloucester (Shannon and Kamp, 1973). A similar study was conducted by the Fisheries Research Board at two aerated sewage lagoons near Winnipeg, Manitoba (Rudd and Hamilton, 1972).

## 1.1     Objectives

In light of the possible environmental effects of NTA on treatment plant operation and the receiving waters, the following areas were investigated in the laboratory and under full scale conditions during the winter of 1972/1973:

1.  Nominal background levels of NTA in sewage treatment plant influent and effluent.
2.  Degradation of NTA in an activated sludge treatment plant.
3.  Effect of NTA loading on the chemical precipitation of phosphorus in a sewage treatment plant.
4.  Effect of NTA loading on heavy metal removal in a sewage treatment plant.
5.  Degradation of NTA in receiving streams.

The test site of the study was the Waterdown Water Pollution Control Plant. The degradation of NTA in receiving streams has already been reported by Shannon et al (1974).

2       STUDY SITE AND EXPERIMENTAL PROCEDURES

2.1     Plant Description

The field test site for the study was the Waterdown Water
Pollution Control Plant built in 1965 as a conventional activated sludge
plant with a design flow of 1 362 $m^3/d$ (0.3 MIGD). The nominal waste-
water flow was approximately 45% of design capacity and all homes served
by the sewer system are within a mile and a half of the treatment plant.
A schematic diagram of the plant is shown in Figure 1, with design
details summarized in Table 1. Throughout the study, the two secondary
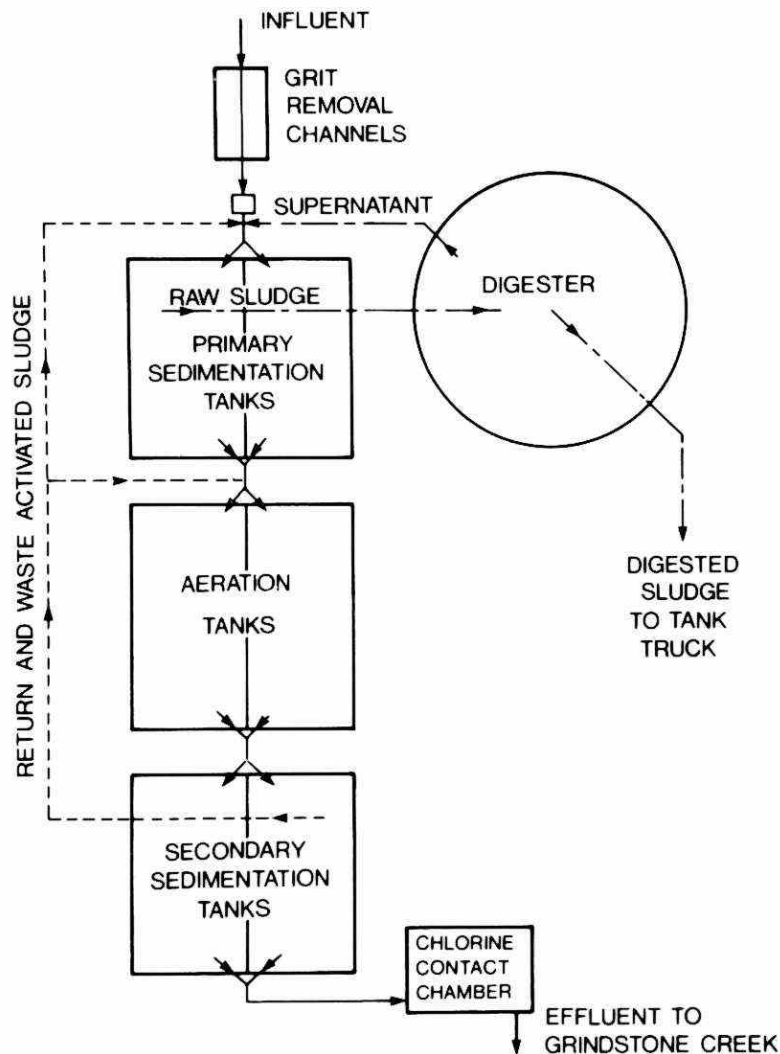
FIGURE 1. WATERDOWN WATER POLLUTION
CONTROL PLANT

sedimentation tanks remained in operation, however, one primary clarifier and one aeration tank were taken out of service. This configuration most closely approached design conditions for the nominal wastewater flow. The effluent from the plant is discharged to Grindstone Creek and eventually finds its way to Hamilton Harbour.

TABLE 1. WATERDOWN WATER POLLUTION CONTROL PLANT
DESIGN DATA. DESIGN FLOW = 1362 m3/d
(0.3 MIGD)

| Process Conv. Act. Sludge | Unit Process | | |
|---|---|---|---|
| | Identification | Description | |
| PRIMARY TREATMENT | Screening | Type<br>Size | : Manually cleaned<br>: One, 2" spacing |
| | Grit Removal | Type | : Channel, manually cleaned |
| | Sedimentation | Type<br>Size<br>Retention<br>Loading | : Walker Process CRP<br>: Two, 30' x 8' x 8' (24 000 gal)<br>: 1.9 hours<br>: Surface 625 gal/ft²/d<br>  Weir 6 520 gal/ft/d |
| SECONDARY (BIOLOGICAL) TREATMENT | Aeration<br><br>Tanks | <br><br>Type<br>Size<br>Retention | <br><br>: Diffused air, single-pass<br>: Two, 90' x 14' x 11' (96 000 gal)<br>: 7.7 hours |
| | Air Supply | Type<br>Size | : Aerzener Blowers<br>: Two, 600 cfm |
| | Diffusers | Type<br>Spacing | : Chicago Pump Discfusers<br>: 48 (total) @ 2' centres |
| | Sedimentation | Type<br>Size<br>Retention<br>Loading | : Walker Process CR<br>: Two, 30' x 8' x 11' (33 000 gal)<br>: 2.6 hours<br>: Surface 625 gal/ft²/d<br>  Weir 6 520 gal/ft/d |
| EFFLUENT DISINFECTION | Chlorination | Feed Capacity:<br>Contactor :<br>Retention : | One, F & P 2-40 lb/d<br>6' x 17' x 8'-9' (5 600 gal)<br>27 minutes |
| SLUDGE HANDLING | Digestion | Type<br><br><br>Size | : Anaerobic, fixed steel cover mixed by<br>  recirculation, single stage<br><br>: One, 30' dia x 17' swd (94 000 gal) |

Note: Multiply - ft x 0.304 = m.
gal x 0.00454 = m³.
lb/d x 0.454 = kg/d.
gal/ft/d x 0.0149 = m³/m·d.
gal/ft²/d x 0.0491 = m³/m²·d.

## 2.2 Experimental Program

The experimental program consisted of the following study conditions during which different chemicals were added to various sewage streams at a number of NTA loadings:

(1) Laboratory study - jar tests concerning the effect of NTA on phosphorus removal.

(2) Field study - aluminum sulphate and NTA addition period.

4

(3)  Field study    - ferric chloride, polymer (Dow A-23)
                      and NTA addition period.

(4)  Field study    - NTA addition period.

A listing of the field study conditions in chronological order is given in Table 2.

TABLE 2.   EXPERIMENTAL FIELD PROGRAM
           AT WATERDOWN

| Field Study Conditions | NTA Spiking Levels[1] | Date | Average NTA Conc. As $H_3NTA$ | Average Temp.[2] °C |
|---|---|---|---|---|
| Baseline | NTA-0, No Alum | Jan 10 - Jan 21 | 3.0 | 11 |
| Alum Addition | NTA-0 | Jan 24 - Feb 11 | 2.7 | 9 |
| | NTA-8 | Feb 14 - Mar 6 | 6.1 | 10 |
| | NTA-16 | Mar 7 - Mar 24 | 14.5 | 9 |
| | | | | |
| | NTA-0 | Apr 11 - Apr 28 | 1.2 | 11 |
| FeCl₃ Addition | NTA-8 | May 1 - May 11 | 10.8 | 12 |
| | NTA-16 | May 15 - May 26 | 19.0 | 15 |
| | NTA-0, No FeCl₃ | May 30 - June 7 | 2.3 | 16 |
| | | | | |
| NTA Addition | NTA-0 | Nov 6 - Nov 19 | 2.0 | 15 |
| | NTA-8 | Dec 4 - Dec 17 | 9.5 | 12 |
| | NTA-16 | Jan 1 - Jan 14 | 21.9 | 10 |
| | | | | |
| NTA Addition | NTA-0 | Jan 29 - Feb 11 | 2.6 | 10 |
| | NTA-8 | Feb 26 - Mar 11 | 7.5 | 10 |
| | NTA-16 | Mar 26 - Apr 5 | 9.0 | 10 |

[1] In mg/L.

## 2.3   Field Procedures

Nitrilotriacetic acid was added to the raw sewage in the form of Sunlight Soap, a commercial laundry detergent. The stock soap solution was made up every morning by adding 0.125 kg of soap per litre of tap water. A constant daily pumping rate was set each morning based upon the raw sewage flow of the previous day and the observed instantaneous flow between 0800 and 0100 hours. The soap solution was added to a manhole approximately 100 m (300 ft) upstream from the head end of the grit channel.

Two chemical types and addition points were used for phosphorus removal during the study. In the first, simultaneous chemical treatment was employed by adding alum to the mixed liquor in the inlet channel to the final clarifier, such that a concentration of 200 mg/L alum was present. The precipitated phosphates were removed along with the activated sludge in the final clarifier. During the second phase,

5

phosphorus removal was accomplished by chemical treatment of raw
sewage. Ferric chloride at 30 mg/L $Fe^{3+}$ was added to the influent end
of the grit removal channel followed by an anionic polymer (Dow A-23)
at 0.5 mg/L to the Parshall Flume. The precipitated phosphates were
removed with the particulates in the primary clarifier. A constant
daily pumping rate (for these chemicals) was determined using the method
developed for the soap solution. The chemical stock solutions were made
up as follows:

1.  Ferric chloride         - 300 g/L.
2.  Alum                     - 640 g/L.
3.  Purifloc A-23 polymer - 2.5 g/L.

## 2.4     Field Sampling Program

Seven points within the Waterdown Water Pollution Control
Plant, as shown in Figure 2, were selected as sampling stations:   raw
sewage main $(S_1)$, effluent channel secondary clarifiers $(S_2)$, effluent
channel primary clarifiers $(S_3)$, aeration tank $(S_4)$, return activated
sludge overflow box $(S_5)$, raw sludge pump $(S_6)$, and the supernatant
return line $(S_7)$. Automatic samplers were set up for the duration of
each study period at $S_1$, $S_2$ and $S_3$. Hourly samples were taken contin-
uously for the sampling period, 24 hours a day. Eight-hour composites
were prepared from these hourly samples for the following three time
periods:   0100 to 0800 hours, 0900 to 1600 hours, and 1700 to 2400 hours.
In the final NTA study period, six-hour composites were prepared from
the hourly samples for the following four time periods:   0100 to
0600 hours, 0700 to 1200 hours, 1300 to 1800 hours and 1900 to 2400 hours.
The resulting data from these samples were used to determine phosphorus
removal and NTA degradation efficiencies measured. Twenty-four-hour
composites were also prepared from these hourly samples. They were used
to assess plant performance by analyzing for total $BOD_5$, suspended
solids, volatile suspended solids, and soluble total organic carbon.
They were also used to measure heavy metal transport by analyzing for
aluminum, iron, copper, zinc and nickel. Grab samples of other streams

were taken in order to gain a more complete understanding of the system. They included: daily grab samples of the aeration tank contents for mixed liquor suspended solids, mixed liquor volatile suspended solids, sludge volume index and total $BOD_5$ plus daily grab samples of the waste activated sludge, raw primary sludge and digester supernatant for suspended solids, volatile suspended solids, iron, aluminum and total phosphorus.
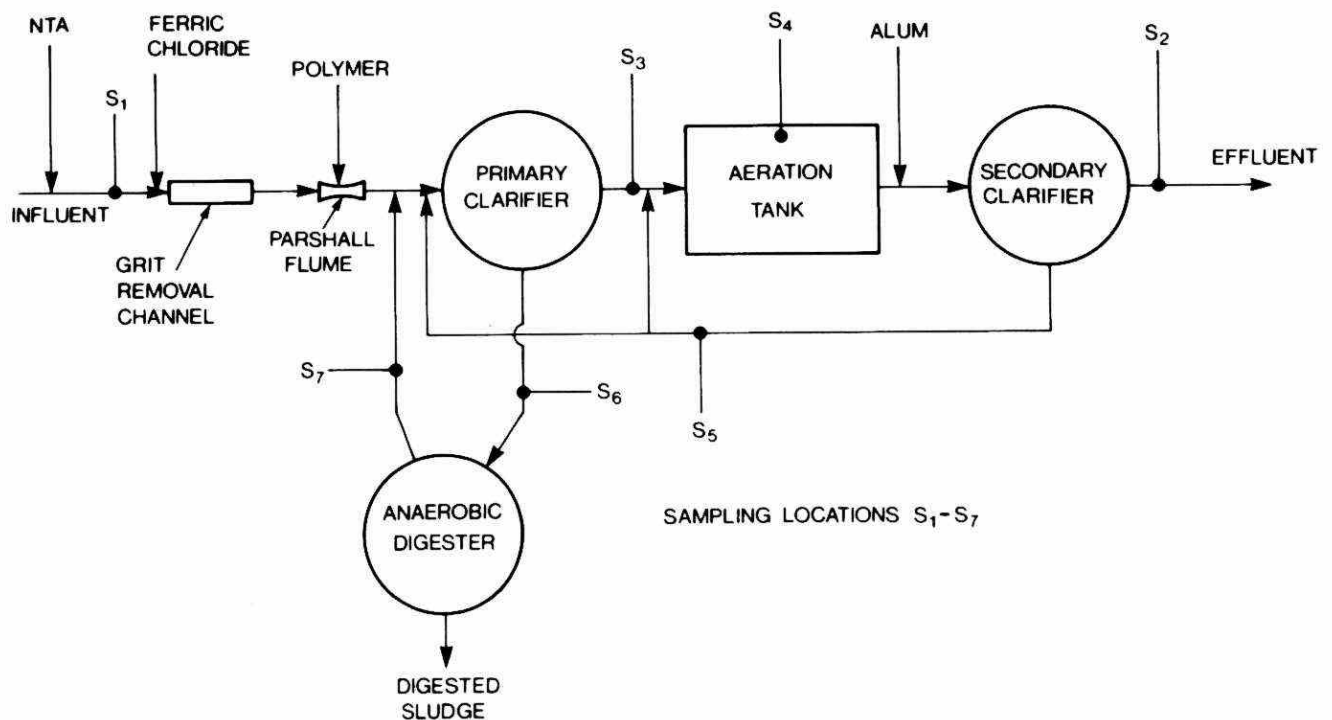


FIGURE 2. TREATMENT PLANT SAMPLING AND CHEMICAL ADDITION LOCATIONS

All routine samples were transported daily to the Wastewater Technology Centre, Burlington, for analyses. Special preservation techniques and analyses were required for some samples, and these are described in a later section.

## 2.5 Jar Testing Procedures

One of the objectives of the study was to assess the relationship between NTA loading and chemical phosphorus removal. For this

7

investigation standard jar testing procedures using Phipps and Bird
six-place gang stirrers were used for the three different phosphorus
removal coagulants (ferric chloride, lime and aluminum sulphate).   A
series of jar tests were conducted on samples from the influent and
effluent streams of several wastewater treatment plants located in the
Burlington area.   The source of the samples and number of jar tests is
shown in Table 3.   After the samples were brought to the laboratory,
they were spiked to the required level of 8 and 16 mg/L of NTA by adding
the sodium salt of NTA.   The ranges of chemical doses tested were as
follows:   lime, 0 to 500 mg/L as $Ca(OH)_2$; ferric chloride, 0 to 30 mg/L
as $Fe^{3+}$; and alum, 0 to 30 mg/L as $Al^{3+}$.   The anionic polymer (Purifloc
A-23, Dow Chemical Company) was used as a coagulant aid at 0.5 mg/L with
ferric chloride and alum.

TABLE 3.   SOURCES OF SEWAGE FOR JAR
TESTS TO ASSESS NTA LOADING
AND CHEMICAL PHOSPHORUS
REMOVAL

| Waste Treatment Plant | Sample Type | No. of Jar Tests |
|---|---|---|
| Waterdown | Raw Sewage | 72 |
| | Secondary Effluent | 23 |
| Skyway Plant Burlington | Raw Sewage | 7 |
| | Secondary Effluent | 27 |
| Drury Lane Plant Burlington | Raw Sewage | 12 |
| | Secondary Effluent | 18 |

The experimental procedures followed for an individual jar
test were:

    (i)   collect 20-litre grab samples of the influent and effluent
streams of the plant and divide each into six, one-litre
beaker aliquots;

    (ii)   add coagulants in the desired concentration and flash mix
the beaker contents at 100 rpm for five minutes;

    (iii)   floculate at 40 rpm for 10 minutes - if polymer was
required, it was added at this stage;

    (iv)   allow samples to settle for 90 minutes at 10 rpm; and

    (v)   discontinue stirring, allowing samples to settle for five
minutes and decant supernatant from each beaker for sub-
sequent analyses.

8

These experimental conditions were followed in an attempt to simulate, as closely as possible, the hydraulic behaviour of a full scale phosphorus removal system. Total phosphorus was measured on all jar test supernatants.

## 2.6 Analytical Procedures

A summary of the parameters measured during the field study is presented in Table 4.

TABLE 4. PARAMETERS EVALUATED DURING STUDY

Raw sewage and primary and secondary effluent ($S_1$, $S_2$, $S_3$)

    total phosphorus
    NTA
    total $BOD_5$
    suspended solids
    volatile suspended solids
    soluble total organic carbon
    heavy metals (Al, Fe, Zn, Cu, Ni)
    temperature
    pH
    dissolved oxygen
    alkalinity
    hardness
    wastewater flow

Aeration tank contents ($S_4$)

    mixed liquor suspended solids
    mixed liquor volatile suspended solids
    sludge volume index
    temperature
    dissolved oxygen
    return activated sludge flow rate

Waste activated and raw primary sludge and digester supernatant ($S_5$, $S_6$, $S_7$)

    total suspended solids
    total volatile suspended solids
    iron
    aluminum
    total phosphorus
    waste activated sludge flow rate
    raw primary sludge flow rate
    digester supernatant flow rate

Suspended and total solids, pH and total alkalinity analyses were conducted in accordance with Standard Methods (1971). Total organic carbon analyses were done on a Beckman Carbon Analyzer. Calcium and total hardness were determined by the EDTA titrimetric method described in Standard Methods (1971) with magnesium calculated from the difference between total hardness and calcium concentrations. Phosphorus analyses were made by the persulphate digestion and automated ascorbic acid method.

Samples taken for NTA analyses were preserved immediately with formaldehyde and filtered as soon as possible through a 0.45 micron

membrane filter. They were then analysed by the polarographic method described by Traversy (1971) which is based on the formation of a bismuth-NTA complex at pH 2.0 ± 0.05. The resultant complex was analysed with a differential cathode ray polarograph.

Samples taken for metal analyses (Fe, Cu, Zn and Ni) were digested with concentrated sulphuric and nitric acid (5 mL of each per 250 mL sample) to dryness. The sample was then made up to 250 mL again with deionized water. If any colour was evident, digestion was repeated using an additional 5 mL of nitric acid. Subsequently, the sample was made up to one litre and heavy metals were determined using the atomic absorption procedures described by Traversy (1971).

## 2.7      Statistical Treatment of Data

Since the primary objective of the project was to assess the various effects of NTA on the treatment plant, it was necessary to find out by how much different groups of data differed, and how statistically significant this difference was. A simple, but effective, analysis of variance technique was used.

For example, the difference between two populations (group) means was estimated by the sample means with a confidence interval as follows:

$$\mu_1 - \mu_2 = \bar{X}_1 - \bar{X}_2 \pm t_{0.025}\ S_p \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

where:     $\mu_1$       = population mean of group 1.

$\mu_2$       = population mean of group 2.

$\bar{X}_1$       = sample mean of group 1.

$\bar{X}_2$       = sample mean of group 2.

$N_1$       = size of sample group 1.

$N_2$       = size of sample group 2.

$t_{0.025}$ = the two-tail "student t" distribution for 95% confidence level.

10

The "pooled" or combined variance is defined as $S_p^2$ of all (in this case, two) sample groups considered (Wannacott & Wannacott, 1969).

If $\mu_1 - \mu_2$ includes zero, that is, $t_{0.025} \, S_p \sqrt{\dfrac{1}{N_1} + \dfrac{1}{N_2}}$ is greater than $\bar{X}_1 - \bar{X}_2$, then the difference is not statistically significant at the 95% confidence level.

When no statistically significant difference is observed between groups, there are the following possible interpretations:

(1) There is no true difference between the populations from which the samples are taken.

(2) The variations of sample values within each group are large. This could be caused by sampling errors, size of samples, etc.

(3) Within group variations are large but there is no true difference.

(4) There is a true difference but it cannot be observed because of the large variations within each group.

In the analysis of raw data, daily averages were used. Since the treatment plant has an inherent retention time, the effect of time lag must be taken into account when analyzing influent and effluent data. The plant was designed with two aeration tanks in parallel for 1 362 $m^3$/d (0.3 MIGD), giving a retention time of eight hours. Throughout this study, the flow rate was approximately half of the design flow and only one aeration tank was used. The retention time for the active plant was approximately 10 hours. In cases where three or four daily composite samples were taken, the time lag effect was reduced by shifting the effluent samples down one composite sample.

3          RESULTS AND DISCUSSION

3.1          Wastewater Characteristics and Treatment Plant Operation

In Table 5 average values for the raw wastewater to the
Waterdown Water Pollution Control Plant are summarized. This provides
a reference for the assessment of the treatment plant behaviour under
various conditions of stress imposed in the course of this study. The
wastewater is typical of a weak municipal wastewater from a low
density residential area. The background NTA and phosphorus loadings
in the raw wastewater averaged 2.5 mg/L and 6.0 mg/L, respectively.
Experimental period averages of the phosphorus and NTA loadings during
periods when there was no NTA addition, are presented in Table 6. The
daily average variation (Figure 3) and diurnal variations (Figures 4 and 5)
of the phosphorus and NTA are also presented. No correlation between
NTA/phosphorus loading and the day of the week was observed. Diurnal
variation studies of the NTA loading showed peak values of approximately
12 mg/L in the afternoon and minimum values of 0.1 mg/L at night.

The experimental period averages of the secondary effluent
characteristics are tabulated in Table 7 and the operational parameters
in Table 8. Although the plant was designed as a conventional activated
sludge system, the F/M ratio and percent return sludge suggest the plant
operation could be more closely approximated by an extended aeration
process. As summarized in Table 7, during most of the experimental
periods an effluent of acceptable quality was produced.

3.2          Impact of NTA on Treatment Plant Operation

3.2.1          General

Laboratory studies by Thompson and Duthie (1968) have shown
that the sedimentation rate and the sludge volume index of raw municipal
wastewater are not affected by the addition of up to 50 mg/L of NTA.
Field studies by Shumate et al (1970) also showed that NTA had no obser-
vable, adverse effects on the overall $BOD_5$ removal efficiency of an
activated sludge plant. Dosages of up to 16 mg/L of NTA were used in
the study.

# TABLE 5.  RAW SEWAGE CHARACTERISTICS

| Experimental Periods / Parameters | NTA-0 Jan 10, 1972 to Jan 21, 1972 | NTA-0+Alum Jan 24, 1972 to Feb 11, 1972 | NTA-8+Alum Feb 14, 1972 to Mar 6, 1972 | NTA-16+Alum Mar 7, 1972 to Mar 24, 1972 | NTA-0+FeCl3 Apr 11, 1972 to Apr 28, 1972 | NTA-8+FeCl3 May 1, 1972 to May 11, 1972 | NTA-16+FeCl3 May 15, 1972 to May 26, 1972 | NTA-0 May 30, 1972 to June 7, 1972 | NTA-0 Nov 6, 1972 to Nov 19, 1972 | NTA-8 Dec 4, 1972 to Dec 17, 1972 | NTA-16 Jan 1, 1973 to Jan 14, 1973 | NTA-0 Jan 29, 1973 to Feb 11, 1973 | NTA-8 Feb 26, 1973 to Mar 11, 1973 | NTA-16 Mar 26, 1973 to Apr 5, 1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $BOD_5$ | 132* (97)** | 69 (21) | 76 (26) | 99 (40) | 62 (30) | 80 (34) | 55 (24) | 52 (20) | 98* (30)** | 109 (82) | 102 (37) | 121 (55) | 119 (35) | 60 (12) |
| TOC | 24 (10) | 83 (57) | 73 (23) | 53 (12) | 27 (12) | 26 (16) | 40 (9) | 27 (12) | 33 (19) | 40 (12) | 28 (10) | 52 (22) | 47 (21) | 27 (6) |
| Phosphorus | 7.3 (2.9) | 7.4 (4.0) | 7.1 (1.4) | 5.8 (3.3) | 3.4 (1.9) | 5.1 (3.0) | 8.3 (4.3) | 6.8 (3.9) | - | - | - | - | - | - |
| Suspended Solids | 105 (47) | 131 (30) | 122 (29) | 106 (26) | 135 (27) | 198 (49) | 204 (65) | 144 (43) | 117 (94) | 57 (28) | 94 (40) | 153 (59) | 133 (34) | 93 (27) |
| Volatile Suspended Solids | 84 (42) | 114 (26) | 106 (26) | 90 (25) | 86 (19) | 119 (23) | 146 (36) | 117 (32) | 84 (51) | 47 (25) | 79 (39) | 118 (34) | 113 (33) | 68 (20) |
| Al | 0.168 (0.040) | 0.177 (0.140) | 0.181 (0.140) | 0.258 (1.410) | 0.175 (0.152) | 0.160 (0.162) | 0.110 (0.075) | 0.221 (0.197) | 0.165 (0.156) | 0.153 (0.118) | 0.174 (0.079) | 0.204 (0.112) | 0.242 (0.139) | 0.214 (0.179) |
| Cu | 0.076 (0.016) | 0.048 (0.02) | 0.067 (0.015) | 0.057 (0.016) | 0.074 (0.026) | 0.086 (0.018) | 0.103 (0.045) | 0.086 (0.025) | 0.119 (0.038) | 0.070 (0.023) | 0.084 (0.029) | 0.091 (0.035) | 0.078 (0.035) | 0.038 (0.017) |
| Fe | 1.10 (1.48) | 0.49 (0.07) | 0.54 (0.18) | 0.62 (0.22) | 9.18 (6.41) | 18.4 (8.74) | 21.6 (12.5) | 3.03 (4.66) | 0.546 (0.272) | 0.274 (0.226) | 0.352 (0.219) | 0.411 (0.263) | 0.506 (0.334) | 0.389 (0.678) |
| Zn | 0.137 (0.080) | 0.173 (0.018) | 0.159 (0.040) | 0.077 (0.040) | 0.161 (0.063) | 0.156 (0.066) | 0.169 (0.073) | 0.194 (0.062) | 0.256 (0.087) | 0.157 (0.055) | 0.189 (0.131) | 0.198 (0.100) | 0.176 (0.073) | 0.111 (0.095) |
| Ni | 0.003 (0.002) | 0.004 (0.001) | 0.009 (0.007) | 0.016 (0.003) | 0.014 (0.002) | 0.017 (0.004) | 0.024 (0.024) | 0.015 (0.002) | - | - | - | - | - | - |
| Pb | - | 0.030 (0.014) | 0.037 (0.027) | 0.017 (0.008) | 0.027 (0.023) | 0.024 (0.008) | 0.028 (0.009) | 0.027 (0.006) | - | - | - | - | - | - |
| Alkalinity | - | - | - | - | 246 (69) | 327 (11) | 381 (33) | - | 562 (50) | 370 (45) | 341 (29) | 343 (33) | 335 (37) | 289 (26) |
| Hardness | - | - | - | - | - | - | - | - | 278 (88) | 471 (176) | 469 (85) | 403 (100) | 270 (67) | 415 (89) |
| Flow | 0.008 (0.010) | 0.077 (0.015) | 0.086 (0.032) | 0.131 (0.043) | 0.182 (0.050) | 0.172 (0.030) | 0.106 (0.030) | 0.103 (0.020) | - | - | - | 0.100 (0.020) | 0.117 (0.060) | 0.220 (0.030) |
| pH | 7.6 (0.8) | 8.0 (0.2) | 7.8 (0.1) | 7.7 (0.2) | 7.5 (0.3) | 7.5 (0.6) | 8.0 (0.2) | 7.8 (0.1) | 7.9 (0.2) | 8.0 (0.1) | 7.9 (0.2) | 7.9 (0.2) | 8.0 (0.1) | 7.9 (0.2) |

*  All parameters in mg/L except pH and flow (flow expressed in MGD).
** Standard deviations in parentheses.

# TABLE 6.  NTA AND PHOSPHORUS CONCENTRATIONS IN RAW SEWAGE

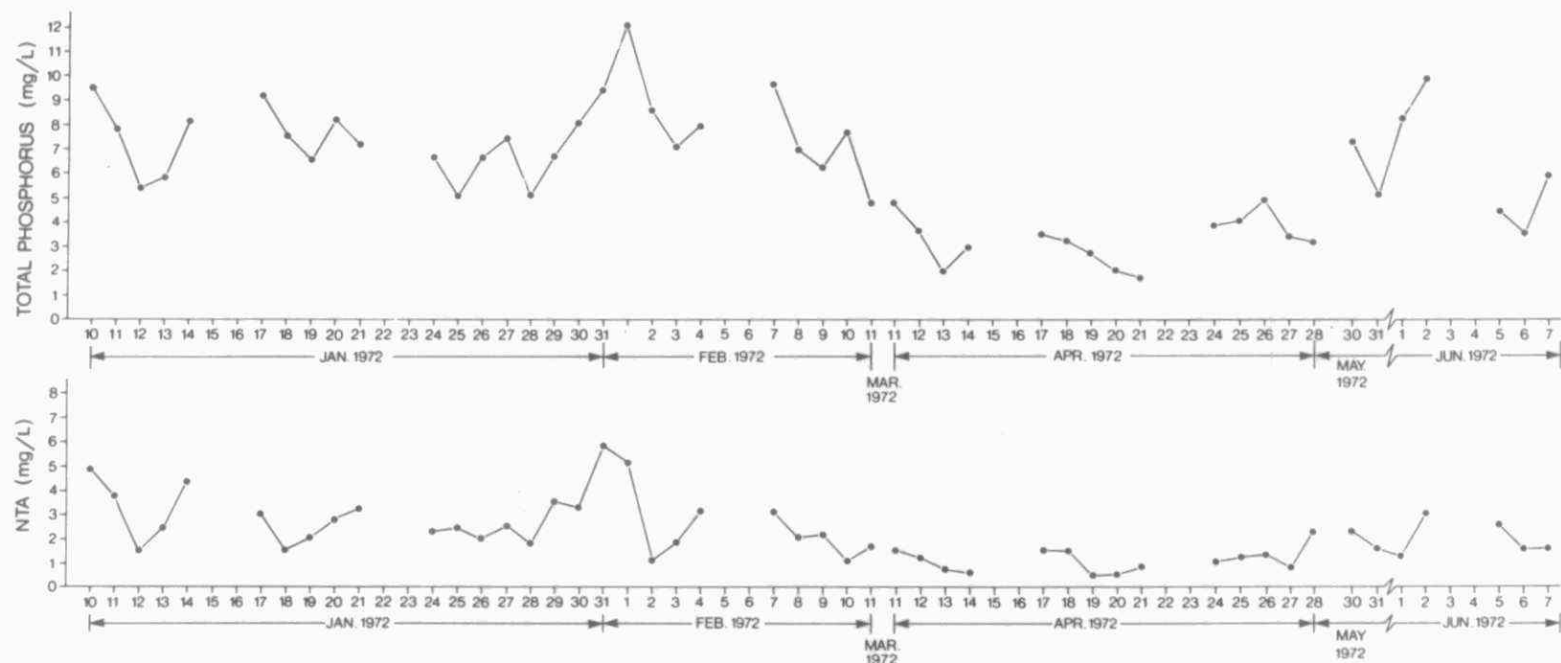| Experimental Period | $H_3$ NTA mg/L | Phosphorus mg/L |
|---|---|---|
| Jan 10 - Jan 21, 1972 | 2.87 (2.24)* | 7.3 (2.9) |
| Jan 24 - Feb 11, 1972 | 2.77 (2.78) | 7.4 (4) |
| Apr 11 - Apr 28, 1972 | 1.16 (1.19) | 3.4 (1.9) |
| May 30 - June 7, 1972 | 2.20 (2.16) | 6.8 (3.9) |
| Nov 6 - Nov 19, 1972 | 1.98 (2.64) | -- |
| Jan 29 - Feb 11, 1973 | 2.55 (6.55) | -- |

* Standard deviations in parentheses.

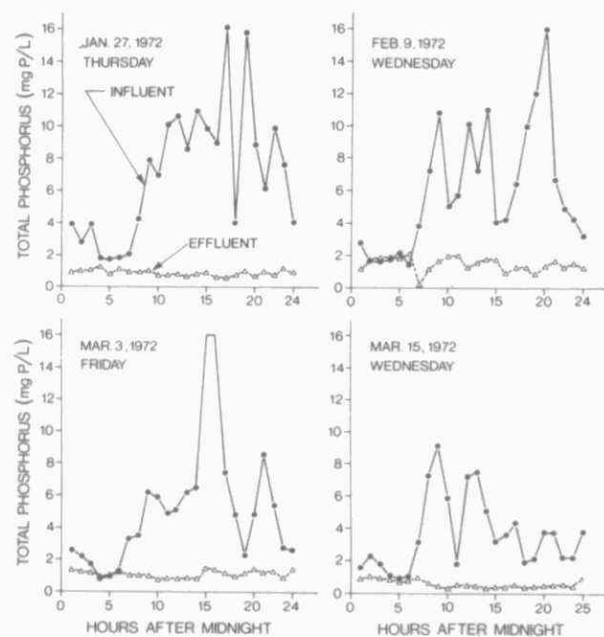FIGURE 3. DAILY TOTAL PHOSPHORUS AND NTA VARIATION IN WATERDOWN RAW WASTEWATER



FIGURE 4. DIURNAL VARIATION OF TOTAL PHOSPHORUS IN RAW
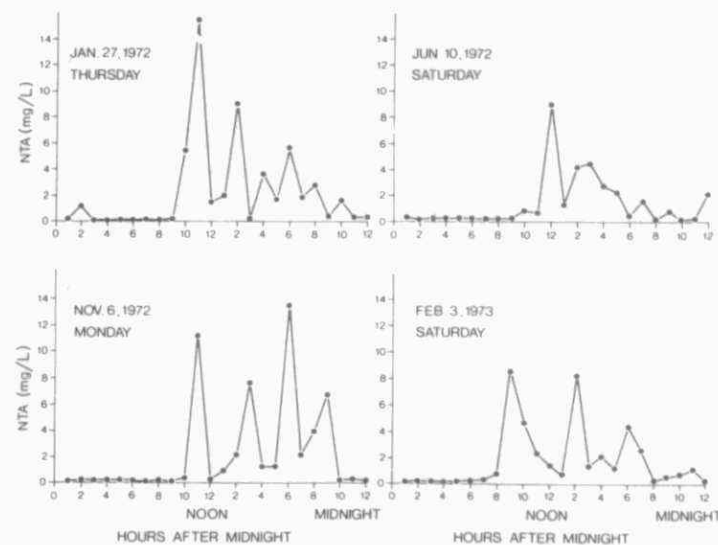WASTEWATER AND SECONDARY EFFLUENT



FIGURE 5. DIURNAL VARIATION OF NTA IN RAW WASTEWATER

14

## TABLE 7. SECONDARY EFFLUENT CHARACTERISTICS

| Experimental Periods / Parameters | NTA-0 Jan 10, 1972 to Jan 21, 1972 | NTA-0+Alum Jan 24, 1972 to Feb 11, 1972 | NTA-8+Alum Feb 14, 1972 to Mar 6, 1972 | NTA-16+Alum Mar 7, 1972 to Mar 24, 1972 | NTA-0+FeCl₃ Apr 11, 1972 to Apr 28, 1972 | NTA-8+FeCl₃ May 1, 1972 to May 11, 1972 | NTA-16+FeCl₃ May 15, 1972 to May 26, 1972 | NTA-0 May 30, 1972 to June 7, 1972 | NTA-0 Nov 6, 1972 to Nov 19, 1972 | NTA-8 Dec 4, 1972 to Dec 17, 1972 | NTA-16 Jan 1, 1973 to Jan 14, 1973 | NTA-0 Jan 29, 1973 to Feb 11, 1973 | NTA-8 Feb 26, 1973 to Mar 11, 1973 | NTA-16 Mar 26, 1973 to Apr 5, 1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BOD₅ | 20* (24)** | 9 (6) | 11 (4) | 17 (7) | 6 (3) | 9 (7) | 12 (4) | 9 (6) | 22* (12)** | 24 (9) | 33 (10) | 11 (9) | 12 (4) | 10 (3) |
| TOC | 3.1 (6.0) | 31.0 (18) | 28.3 (9.1) | 28.6 (9.7) | 18 (9) | 14 (4) | 15 (1) | 12 (6) | 21 (7) | 38 (23) | 22 (5) | 19 (4) | 24 (5) | 19 (2) |
| Phosphorus | 8.3 (1.5) | 1.9 (1.1) | 1.5 (0.6) | 0.96 (0.30) | 0.5 (0.2) | 0.5 (0.1) | 0.8 (0.5) | 3.0 (1.8) | - | - | - | - | - | - |
| Suspended Solids | 48 (75) | 22 (9) | 29 (7) | 25 (3) | 9 (3) | 10 (3) | 14 (9) | 12 (9) | 15 (5) | 10 (6) | 10 (4) | 10 (5) | 13 (6) | 9 (3) |
| Volatile Suspended Solids | 12 (7) | 16 (5) | 22 (6) | 20 (3) | 7 (4) | 8 (3) | 12 (9) | 10 (8) | 13 (5) | 8 (5) | 3 (3) | 8 (3) | 10 (5) | 7 (2) |
| Al | 0.136 (0.074) | 0.658 (0.450) | 0.717 (0.587) | - | 0.063 (0.030) | 0.042 (0.011) | 0.028 (0.007) | 0.111 (0.085) | 0.075 (0.064) | 0.105 (0.078) | 0.118 (0.066) | 0.072 (0.044) | 0.120 (0.081) | 0.120 (0.046) |
| Cu | 0.037 (0.008) | 0.015 (0.007) | 0.023 (0.007) | 0.025 (0.005) | 0.021 (0.006) | 0.015 (0.003) | 0.015 (0.002) | 0.025 (0.007) | 0.064 (0.039) | 0.031 (0.025) | 0.038 (0.019) | 0.025 (0.030) | 0.030 (0.028) | 0.025 (0.014) |
| Fe | 0.275 (0.350) | 0.173 (0.080) | 0.275 (0.100) | 0.325 (0.130) | 0.630 (0.347) | 0.700 (0.394) | 0.670 (0.279) | 0.340 (0.450) | 0.324 (0.124) | 0.083 (0.046) | 0.167 (0.077) | 0.095 (0.057) | 0.249 (0.218) | 0.134 (0.123) |
| Zn | 0.063 (0.056) | 0.110 (0.037) | 0.138 (0.040) | 0.129 (0.130) | 0.058 (0.020) | 0.098 (0.037) | 0.113 (0.062) | 0.081 (0.015) | 0.182 (0.055) | 0.128 (0.022) | 0.179 (0.122) | 0.097 (0.039) | 0.174 (0.030) | 0.077 (0.054) |
| Ni | 0.002 (0.002) | 0.003 (0.001) | 0.009 (0.008) | 0.014 (0.003) | 0.009 (0.002) | 0.010 (0.002) | 0.009 (0.002) | 0.009 (0.003) | - | - | - | - | - | - |
| Pb | 0.005 (0.003) | 0.013 (0.0180) | 0.0184 (0.018) | 0.010 (0.008) | 0.005 (0.002) | 0.005 (0.005) | 0.005 (0.002) | 0.005 (0.001) | - | - | - | - | - | - |
| pH | 7.0 (0.1) | 7.0 (0.1) | 7.0 (0.1) | 7.1 (0.1) | 7.2 (0.1) | 7.0 (0.2) | 7.2 (0.1) | 7.1 (0.1) | 7.4 (0.1) | 7.0 (1.4) | 7.2 (1.3) | 7.4 (0.1) | 7.4 (0.1) | 7.5 (0.1) |

\* All parameters in mg/L except pH.
\*\* Standard deviations in parentheses.

15

## TABLE 8. WATERDOWN POLLUTION CONTROL PLANT OPERATIONAL CHARACTERISTICS

| Experimental Periods | % BOD Removal | % Return Sludge | Aeration Time h | MLSS mg/L | MLVSS mg/L | Temp. °C | F/M | DO mg/L | SVI |
|---|---|---|---|---|---|---|---|---|---|
| NTA-0, Jan 10-21, 1972 | 87 | 33 | 9.8 | 2 089 | 1 792 | 11 | 0.13 | 2.4 | 123 |
| NTA-0+Alum, Jan 24 - Feb 11, 1972 | 85 | 89 | 7.9 | 2 756 | 1 963 | 9 | 0.06 | 2.3 | 165 |
| NTA-8+Alum, Feb 14 - Mar 6, 1972 | 86 | 97 | 6.8 | 2 866 | 1 912 | 10 | 0.08 | 3.2 | 228 |
| NTA-16+Alum, Mar 7-24, 1972 | 80 | 74 | 5.1 | 3 691 | 2 488 | 9 | 0.10 | 5.7 | 161 |
| NTA-0+FeCl₃, Apr 11-28, 1972 | 88 | 67 | 3.8 | 2 709 | 1 997 | 11 | 0.12 | 6.0 | 109 |
| NTA-8+FeCl₃, May 1-11, 1972 | 86 | 69 | 4.0 | 2 861 | 2 098 | 12 | 0.14 | 4.1 | 161 |
| NTA-16+FeCl₃, May 15-26, 1972 | 79 | 33 | 8.2 | 2 474 | 1 836 | 15 | 0.07 | 2.7 | 125 |
| NTA-0, May 30 - June 7, 1972 | 84 | 88 | 5.9 | 2 623 | 1 927 | 16 | 0.06 | 1.0 | 114 |
| NTA-0, Nov 6-19, 1972 | 75 | 34 | - | 1 645 | 1 350 | 15 | - | 3.6 | 578 |
| NTA-8, Dec 4-17, 1972 | 73 | 28 | - | 1 484 | 1 169 | 12 | - | 4.4 | 516 |
| NTA-16, Jan 1-14, 1973 | 66 | 30 | - - | 1 463 | 1 169 | 10 | - | 4.9 | 498 |
| NTA-0, Jan 29 - Feb 11, 1973 | 92 | 29 | 8.6 | 1 477 | 1 216 | 10 | 0.21 | 4.8 | 667 |
| NTA-8, Feb 26 - Mar 11, 1973 | 88 | 53 | 6.4 | 2 324 | 1 861 | 10 | 0.16 | 4.1 | 394 |
| NTA-16, Mar 26 - Apr 5, 1973 | 82 | 42 | 3.7 | 2 212 | 1 579 | 10 | 0.17 | 3.8 | 167 |

### 3.2.2 Treatment plant efficiency

The $BOD_5$ and suspended solids removal efficiencies in this study were monitored routinely during all the experimental periods. Table 9 shows that in each period the percent $BOD_5$ removal decreased slightly with increasing NTA level. The fact that this trend was evident in all four periods leads to the hypothesis that high levels of NTA do have some adverse effect on plant operation. To test this hypothesis, the data in Table 9 are grouped into the three NTA levels and an analysis of variance carried out. The statistical data presented in Table 10 shows that there was a slight, but statistically significant, decrease in $BOD_5$ removal at an NTA level of 16 mg/L.

TABLE 9. INFLUENT NTA CONCENTRATIONS AND TREATMENT PLANT $BOD_5$ AND SUSPENDED SOLIDS REMOVAL FOR EACH EXPERIMENTAL PERIOD

| Experimental Periods | Date | NTA Level mg/L | % $BOD_5$ Removal | % Suspended Solids Removal |
|---|---|---|---|---|
| NTA-0 No Alum | Jan 10 - Jan 21 | 3.0 | 86.5 (6.7)* | 85.2 (3.2) |
| NTA-0 Alum | Jan 24 - Feb 11 | 2.7 | 84.4 (9.4) | 83.1 (5.6) |
| NTA-8 Alum | Feb 14 - Mar 6 | 6.1 | 85.3 (5.6) | 73.8 (10.0) |
| NTA-16 Alum | Mar 7 - Mar 24 | 14.5 | 79.9 (9.8) | 74.5 (8.4) |
| NTA-0 $FeCl_3$ | Apr 11 - Apr 28 | 1.2 | 88.0 (9.9) | 93.0 (3.1) |
| NTA-8 $FeCl_3$ | May 1 - May 4 | 10.8 | 86.4 (11.0) | 94.6 (1.9) |
| NTA-16 $FeCl_3$ | May 15 - May 26 | 19.0 | 78.9 (8.4) | 92.8 (4.8) |
| NTA-0 | May 30 - June 7 | 2.3 | 83.5 (7.8) | 91.9 (3.9) |
| NTA-0 | Nov 6 - Nov 19 | 2.0 | 74.9 (16.2) | 80.8 (11.8) |
| NTA-8 | Dec 4 - Dec 17 | 9.5 | 73.0 (11.8) | 81.3 (10.5) |
| NTA-16 | Jan 1 - Jan 14 1973 | 21.9 | 65.5 (10.6) | 88.9 (2.6) |
| NTA-0 | Jan 29 - Feb 11 | 2.6 | 91.5 (3.9) | 92.6 (6.0) |
| NTA-8 | Feb 26 - Mar 11 | 7.5 | 87.6 (6.2) | 89.4 (4.9) |
| NTA-16 | Mar 26 - Apr 5 | 9.0 | 81.8 (7.3) | 89.1 (3.5) |

* Standard deviations in parentheses.

TABLE 10.   EFFECT OF NTA LOADING ON BOD$_5$ AND
SUSPENDED SOLIDS REMOVAL

| | Average NTA Level mg/L H$_3$NTA | Average Temp °C | % BOD$_5$ Removal | | | % Suspended Solids Removal | | |
|---|---|---|---|---|---|---|---|---|
| | | | n | Average | Standard Deviation | n | Average | Standard Deviation |
| $\mu_1$ | 2.3 | 11.5 | 69 | 85.2 | 10.3 | 69 | 87.7 | 7.7 |
| $\mu_2$ | 8.3 | 10.8 | 40 | 82.9 | 10.4 | 41 | 83.4 | 11.5 |
| $\mu_3$ | 16.0 | 10.6 | 43 | 78.1 | 11.0 | 42 | 84.7 | 10.6 |
| $\mu_1 - \mu_2 =$ | | | | 2.3 ± 4.0  NS | | | 4.3 ± 3.6  S | |
| $\mu_1 - \mu_3 =$ | | | | 7.1 ± 4.1  S | | | 3.0 ± 3.4  NS | |
| $\mu_2 - \mu_3 =$ | | | | 4.8 ± 4.7  NS | | | -0.7 ± 4.8  NS | |

NS = Not significant at the 95% confidence level.
S = Significant at the 95% confidence level.

## 3.3     Effect of NTA on Chemical Precipitation of Phosphorous

### 3.3.1     General

When ferric or aluminum salts are added to wastewater con-
taining phosphates, the metals react with the phosphate anions to
precipitate phosphorus.   In the presence of NTA, one would expect the
chelating capacity of the NTA to compete with the phosphate anions for
the metallic ions, thereby resulting in a reduced phosphorus removal
efficiency.

Forsberg and Wiberg (1968) treated sewage effluent with
100 mg/L of aluminum sulphate in the presence of 0, 1, 5 and 10 mg/L of
NTA.   The phosphorus removal efficiency was observed to decrease by
about 10% between 0 and 10 mg/L NTA.   However, the statistical signi-
ficance of the results was not clear.   Bouveng et al (1968) also
reported qualitative results indicating a slight decrease in phosphorus
removal with alum at NTA levels from 0 to 10 mg/L.   Gudernatsch (1970)
reported that the influence of NTA on phosphorus removal with lime was
insignificant and the results with ferric and alum salts were similar to
Bouveng's.   The NTA concentration under study was 25 mg/L as Na$_3$NTA·H$_2$O.

### 3.3.2     Bench scale studies

To elucidate on the above observations, a series of jar
tests were carried out in the laboratory using domestic sewage with
different levels of NTA and chemical precipitants.   The results are
presented in Tables 11 and 12.   An analysis of variance on the

17

experimental data showed that the presence of up to 16 mg/L of NTA had no effect on chemical precipitation of phosphorus when using alum or ferric chloride.

TABLE 11.  BENCH SCALE EVALUATION OF THE IMPACT OF NTA ON PHOSPHORUS REMOVAL IN RAW SEWAGE

| Coagulant | Replicates | Mean Percent Removal As A Function of NTA And Coagulant Dosage | | | | | | | Analysis Of Variance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NTA mg/L | Coagulant Dosage mg/L | | | | | | Source of Variation | Sum of Squares | Degrees of Freedom | Mean Squares | $F_c$ | $F_{0.005}$ |
| | | | 0.0 | 5.0 | 10.0 | 15.0 | 20.0 | 30.0 | | | | | | |
| Ferric Chloride | 6 | 0.0 | 0.0 | 21.8 | 39.7 | 49.5 | 61.4 | 73.7 | NTA | 1 749.0 | 2 | 874.5 | 8.58 | 3.10 |
| | | 8.0 | 0.0 | 24.0 | 34.9 | 46.9 | 57.7 | 72.7 | Coagulant Dosage | 70 819.0 | 5 | 14 163.8 | 139.00 | 2.33 |
| | | 16.0 | 0.0 | 22.5 | 50.8 | 62.6 | 70.9 | 84.9 | NTA x Coagulant Dosage | 1 019.0 | 10 | 101.9 | 1.12 | 1.95 |
| | | | | | | | | | Error | 8 159.0 | 90 | 90.7 | | |
| Alum | 6 | 0.0 | 0.0 | 38.5 | 64.1 | 80.7 | 88.9 | 93.1 | NTA | 187.6 | 2 | 93.8 | 1.22 | 3.10 |
| | | 8.0 | 0.0 | 47.9 | 63.5 | 76.0 | 86.1 | 91.8 | Coagulant Dosage | 109 903.0 | 5 | 21 980.6 | 285.41 | 2.33 |
| | | 16.0 | 0.0 | 44.6 | 75.0 | 83.0 | 86.7 | 92.9 | NTA x Coagulant Dosage | 770.1 | 10 | 77.0 | 1.02 | 1.95 |
| | | | | | | | | | Error | 6 779.9 | 90 | 75.3 | | |

TABLE 12.  BENCH SCALE EVALUATION OF THE IMPACT OF NTA ON PHOSPHORUS REMOVAL IN SECONDARY EFFLUENT

| Coagulant | Replicates | Mean Percent Removal As A Function Of NTA And Coagulant Dosage | | | | | | | Analysis Of Variance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NTA mg/L | Coagulant Dosage mg/L | | | | | | Source of Variation | Sum of Squares | Degrees of Freedom | Mean Squares | $F_c$ | $F_{0.005}$ |
| | | | 0.0 | 5.0 | 10.0 | 15.0 | 20.0 | 30.0 | | | | | | |
| Ferric Chloride | 6 | 0.0 | 0.0 | 27.1 | 44.8 | 61.1 | 75.4 | 84.5 | NTA | 363.7 | 2 | 181.9 | 9.78 | 3.90 |
| | | 8.0 | 0.0 | 33.0 | 52.3 | 62.0 | 76.2 | 85.9 | Coagulant Dosage | 85 357.3 | 5 | 17 071.5 | 918.14 | 2.33 |
| | | 16.0 | 0.0 | 28.1 | 44.6 | 57.4 | 70.5 | 82.8 | NTA x Coagulant Dosage | 185.9 | 10 | 18.6 | 0.13 | 1.95 |
| | | | | | | | | | Error | 13 381.2 | 90 | 148.7 | | |
| Alum | 6 | 0.0 | 0.0 | 53.9 | 75.3 | 85.4 | 90.5 | 93.5 | NTA | 29.1 | 2 | 14.5 | 2.16 | 3.09 |
| | | 8.0 | 0.0 | 54.4 | 75.5 | 81.6 | 88.5 | 92.5 | Coagulant Dosage | 128 632.8 | 5 | 25 726.6 | 3 821.02 | 2.32 |
| | | 16.0 | 0.0 | 54.6 | 74.3 | 83.9 | 88.9 | 91.2 | NTA x Coagulant Dosage | 67.3 | 10 | 6.7 | 0.15 | 1.95 |
| | | | | | | | | | Error | 4 850.1 | 108 | 44.9 | | |

### 3.3.3    Field studies

The effect of NTA on the chemical precipitation of phosphorus was also examined at field scale.  Table 13 indicates the effect of NTA on primary phosphorus removal by $FeCl_3$.  The removal increased by 5.4% between 1.2 and 10.8 mg/L NTA and by 7.3% between 1.2 and 19.2 mg/L NTA. No significant difference was observed between 10.8 and 19.2 mg/L NTA. It should be observed that the slight increases are just barely significant and phosphorus removal has increased rather that decreased.

TABLE 13.  EFFECT OF NTA ON PHOSPHORUS REMOVAL WITH $FeCl_3$

| | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % Phosphorus Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|
| $\mu_1$ | 1.2 | 10.5 | 14 | 83.97 | 633.13 | 6.9 |
| $\mu_2$ | 10.8 | 12.0 | 10 | 89.36 | 195.56 | 4.7 |
| $\mu_3$ | 19.2 | 14.5 | 11 | 91.26 | 55.61 | 2.4 |
| | | | 35 | | 884.30 | |

$$S_p^2 = \frac{884.30}{32} = 27.63 \qquad S_p = 5.26 \qquad t_{0.05} = 2.042$$

$$\mu_1 - \mu_2 = -5.39 \pm 10.74\sqrt{\frac{1}{14} + \frac{1}{10}} = -5.39 \pm 4.4 \qquad S$$

$$\mu_1 - \mu_3 = -7.29 \pm 10.74\sqrt{\frac{1}{14} + \frac{1}{11}} = -7.29 \pm 4.3 \qquad S$$

$$\mu_2 - \mu_3 = -1.9 \pm 10.74\sqrt{\frac{1}{10} + \frac{1}{11}} = -1.9 \pm 4.7 \qquad NS$$

NS = Not significant at the 95% confidence level.
S = Significant at the 95% confidence level.

The NTA effect when alum was added to the aeration tank is shown in Table 14.  No statistically significant difference was observed.  In the field study at Gloucester (Shannon and Kamp, 1973) no quantifiable effect on phosphorus removal was observed with either alum, $FeCl_3$ or lime in the presence of increased NTA levels. The results obtained from the Waterdown field study confirm the findings in the bench scale jar tests and the published literature. Nitrilotriacetic acid dosages up to 16 mg/L do not adversely affect the chemical precipitation of phosphorus in the activated sludge process.

TABLE 14.   EFFECT OF NTA ON PHOSPHORUS REMOVAL WITH ALUM

| | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % Phosphorus Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|
| $\mu_1$ | 2.8 | 9.4 | 17 | 73.15 | 2 476.88 | 12.4 |
| $\mu_2$ | 6.4 | 9.7 | 17 | 78.57 | 985.58 | 7.8 |
| $\mu_3$ | 14.0 | 9.2 | 16 | 76.08 | 3 047.75 | 14.3 |
| | | | 50 | | 6 510.21 | |

$$S_p^2 = \frac{6\ 510.21}{47} = 138.52 \qquad S_p = 11.769 \qquad t_{0.05} = 2.01$$

$$\mu_1 - \mu_2 \;=\; -5.42 \pm 23.66\sqrt{\tfrac{1}{17} + \tfrac{1}{17}} \;=\; -5.42 \pm 8.12 \qquad \text{NS}$$

$$\mu_1 - \mu_3 \;=\; -2.93 \pm 23.66\sqrt{\tfrac{1}{17} + \tfrac{1}{16}} \;=\; -2.93 \pm 8.26 \qquad \text{NS}$$

$$\mu_2 - \mu_3 \;=\; 2.49 \pm 23.66\sqrt{\tfrac{1}{17} + \tfrac{1}{16}} \;=\; 2.49 \pm 8.26 \qquad \text{NS}$$

NS = Not significant at the 95% confidence level.

## 3.4      NTA Degradation in the Treatment Plant

### 3.4.1     General

Earlier studies have indicated that NTA is biodegradable and is removed by the conventional activated sludge process (Thompson and Duthie, 1968). It has also been reported that NTA does not affect normal treatment plant operation (Shumate et al, 1970). A general impression of NTA removal may be obtained by examining Figure 6 (a), (b) and (c) where typical influent NTA concentrations and the overall amount removed are plotted. Figure 7 (a), (b) and (c) show examples of overall NTA removal (in percent removal) and NTA input concentration. It may be seen from the Figures that the amount of NTA removed follows the input NTA concentration closely and there is a general trend that the removal rate decreases with increasing NTA concentration. That is, the rate of NTA removal by acclimated sludges is a first order reaction. For the case of stoichiometric NTA-metal complexes, Shannon et al (1978) also determined from batch data that biodegradation of these complexes could be approximated by a first order reaction. The overall removal

FIGURE 6. NTA DEGRADATION

(a)

(b) TEMP.                    9.7°C
    AVE. NTA                6.1 mg/L
    AVE. NTA REMOVED 75.9 %

------- INPUT NTA
——— % NTA REMOVED

(c)

TEMP.                    9.2°C
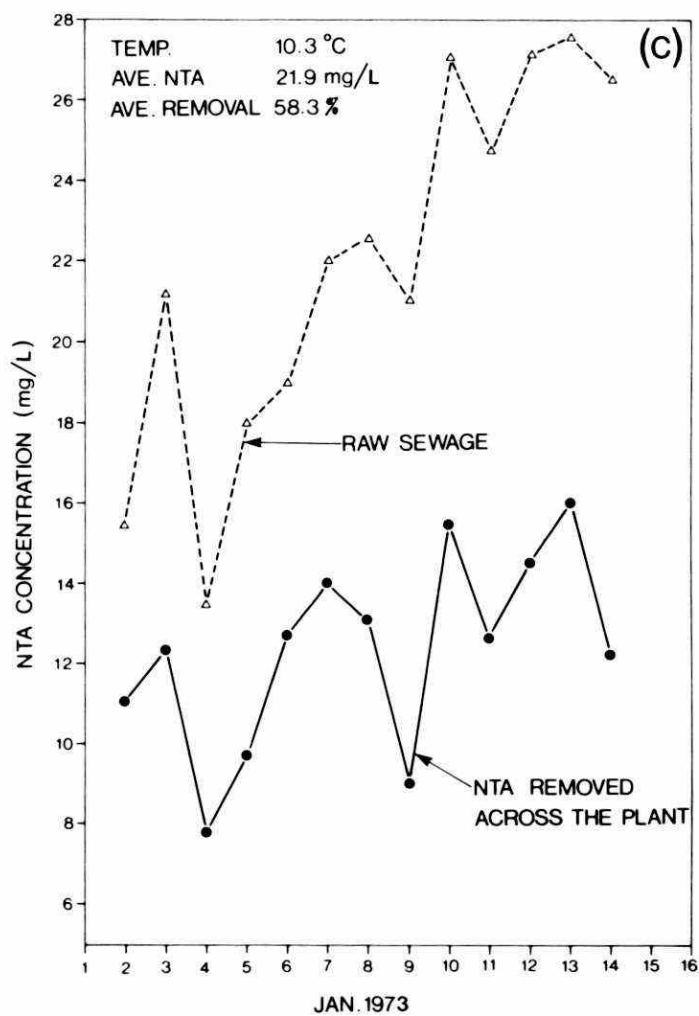AVE. NTA                14.5 mg/L
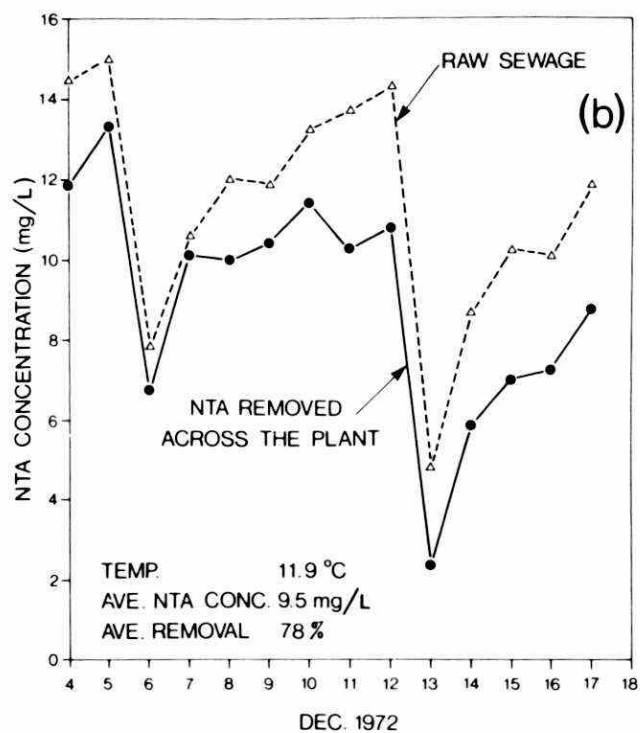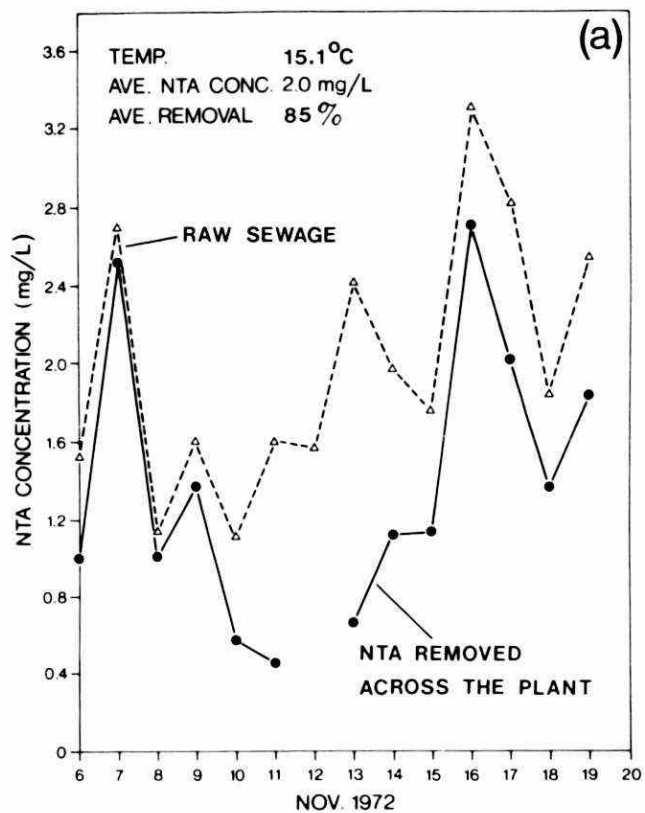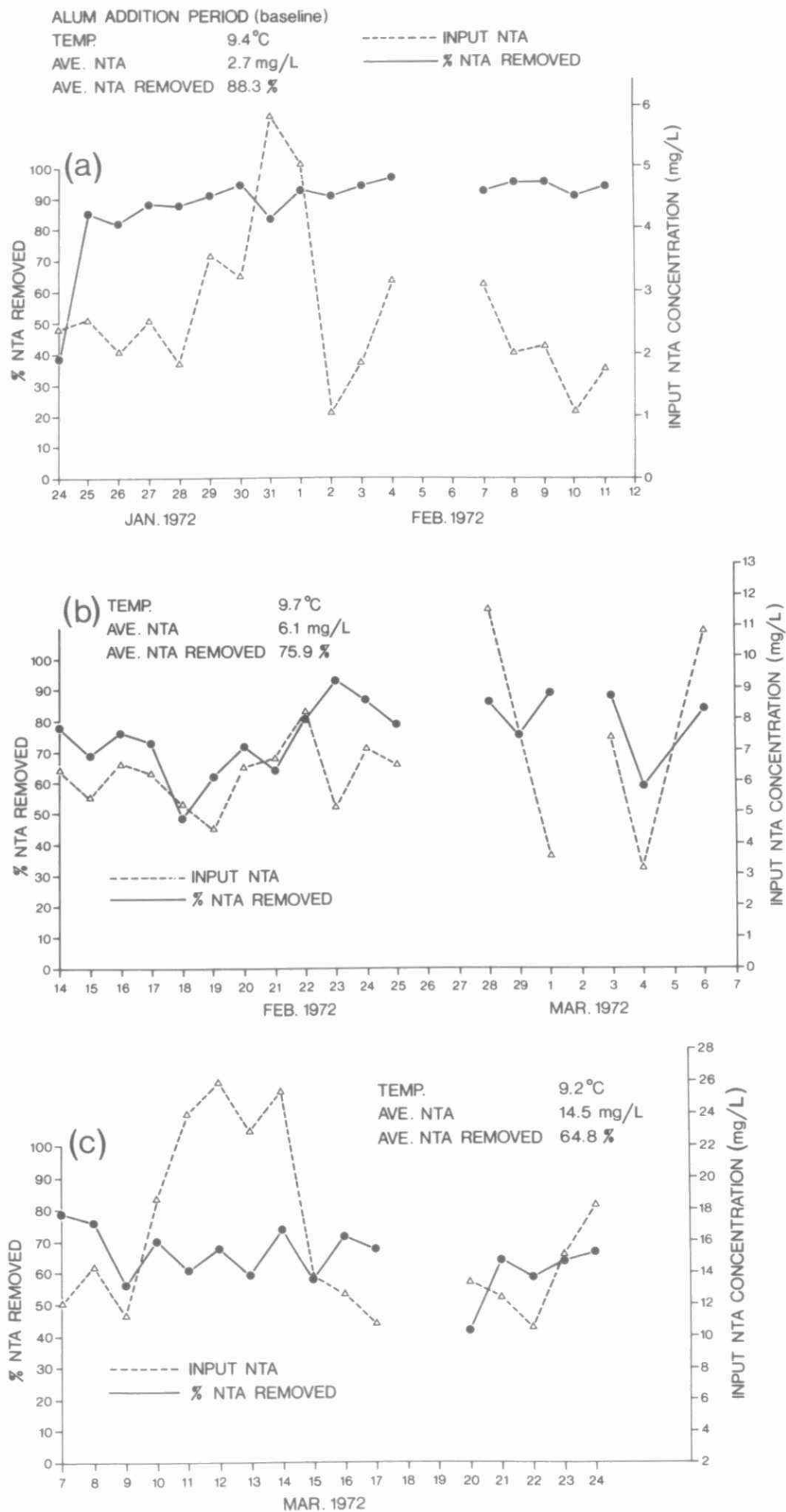AVE. NTA REMOVED 64.8 %

------- INPUT NTA
——— % NTA REMOVED

FIGURE 7.  PERCENT NTA REMOVAL AS A FUNCTION OF INLET NTA CONCENTRATION

22

of NTA through the plant (primary settling and activated sludge
treatment) has been used throughout the report. This is because data
from this investigation and that of others has shown that negligible
removal occurs in primary clarification. Thus, the removals shown are
attributed to the secondary process only.

3.4.2    Acclimatization of microorganisms to NTA

Spiking synthetic sewage in a laboratory size unit with NTA,
Swisher et al (1967) found that two to three weeks acclimation were
needed before NTA degradation would proceed smoothly for fresh activated
sludge. In separate studies, Bouveng et al (1968) found a 35 to 40-day
acclimation period was required with sewage in bench and pilot scale
units. In their study, Shumate et al (1970) used five weeks of
acclimatization for the 2 mg/L NTA level, one week for the following
8 mg/L NTA addition period, and none for the 16 mg/L NTA period. A
significant finding in Shumate's work was that an acclimatization period
was not necessary for an increase in NTA dosage from 8 to 16 mg/L, as
long as the sewage was already well acclimatized at 8 mg/L. Cleasby
et al (1974) found that an increase in NTA feed concentration from
4 to 8 mg/L caused no increase in effluent NTA, but an increase to
16 mg/L did show a higher initial concentration of NTA in the effluent.
However, only a few days were required to acclimate the system.
Renn (1974), who was studying NTA loading on a package treatment plant,
found that a three-month acclimation period was required when the NTA
level was shifted from 0.5 to 30 mg/L. Shannon et al (1978) observed
that in batch studies of biodegradation of various NTA-metal complexes,
acclimation generally occurred in less than seven days. The general
conclusion to be drawn from these studies is that an acclimation period
is required for sludge which has not been previously exposed to NTA.

Acclimation periods were also observed in this study. During
the alum addition period, three NTA dosage levels were studied con-
secutively without periods of acclimatization in between. As indicated
in Figure 8, there was a noticeable drop in NTA removal on February 14
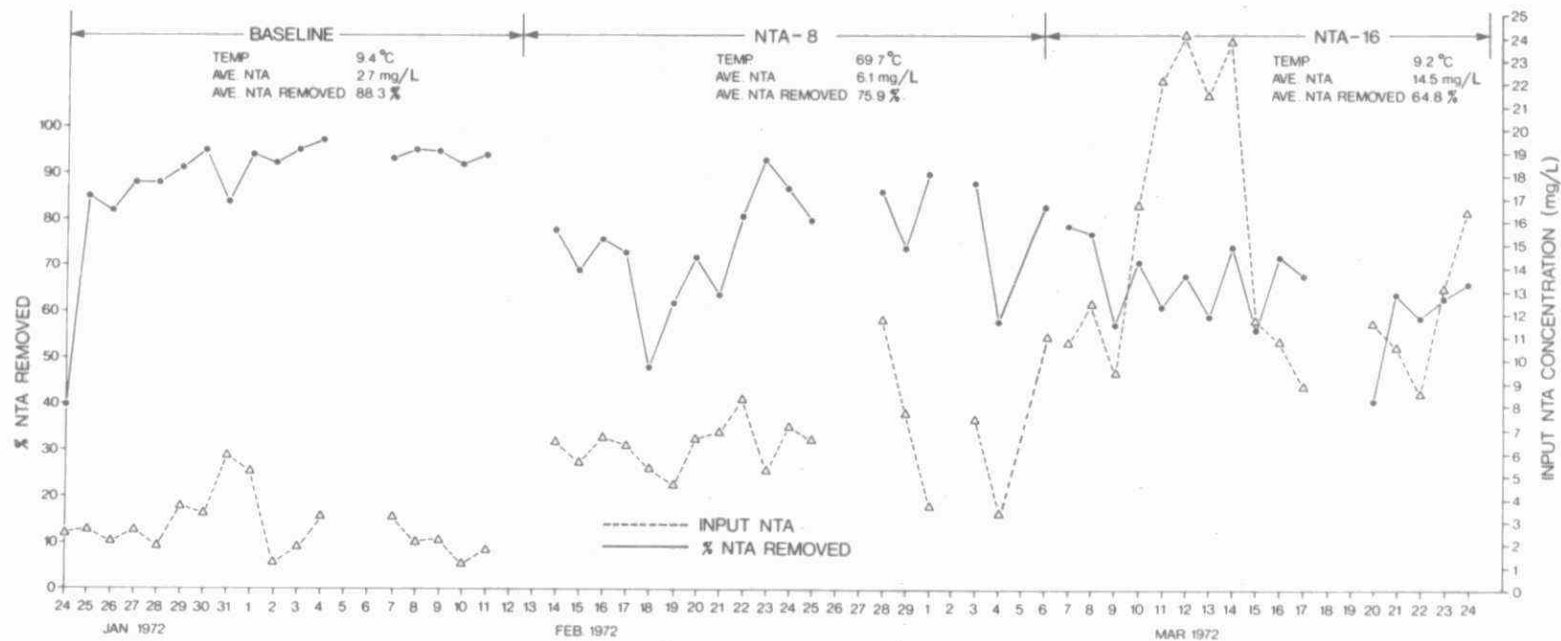when the NTA level was increased to 6.5 mg/L from a baseline value of

FIGURE 8. EFFECT OF NTA SHOCK LOADING ON NTA REMOVAL

about 2 mg/L. A similar, but not as pronounced a drop may be noted on March 10 when the NTA level increased from 9 to 24 mg/L. During the NTA addition period from January 29, 1973 to March 8, 1973, there was a two-week acclimation period between NTA spiking levels. Even after the two-week acclimation period, there was still some initial reduction in NTA removal as a result of the transition from 2.6 to 7.5 mg/L NTA.

The Waterdown data demonstrated that an acclimation period is required following an increase in NTA loading even when the sludge has been subjected to NTA for prolonged periods. For NTA loading step changes of 5 to 10 mg/L, the acclimation period appears to be approximately three weeks.

### 3.4.3    Chemical addition

The effect of alum and ferric chloride additions on NTA degradation is demonstrated in Tables 15 and 16. Both chemical additions fail to indicate a statistically significant difference in NTA removal between samples with and without chemical addition. The sets of data were chosen for analyses on the basis of constant temperature and NTA dosage.

TABLE 15. EFFECT OF ALUM ADDITION ON NTA REMOVAL

| | Precipitant | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % NTA Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|---|
| $\mu_1$ | No Alum | 3.0 | 11.0 | 9 | 78.8 | 1 788.22 | 14.9 |
| $\mu_2$ | With Alum | 2.7 | 9.4 | 17 | 88.3 | 2 798.26 | 13.2 |
| | | | | 26 | | 4 586.48 | |
| | $S_p^2 = \dfrac{4\ 586.48}{24}$ | | | | $S_p = 13.82$ | $t_{0.05} = 2.064$ | |
| | $\mu_1 - \mu_2 \quad = \quad -9.5 \pm 28.53\sqrt{\dfrac{1}{9}+\dfrac{1}{17}} \quad = \quad -9.5 \pm 11.76$ | | | | | | NS |

NS = Not significant at the 95% confidence level.

25

TABLE 16. EFFECT OF $FeCl_3$ ADDITION ON NTA REMOVAL

| | Precipitant | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % NTA Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|---|
| $\mu_1$ | No $FeCl_3$ | 9.5 | 12.0 | 14 | 78.64 | 1 989.83 | 12.4 |
| $\mu_2$ | With $FeCl_3$ | 10.8 | 12.0 | 10 | 68.21 | 3 425.01 | 19.5 |
| | | | | 24 | | 5 414.84 | |

$$S_p^2 = \frac{5\ 414.84}{22} \qquad S_p^2 = 15.68 \qquad t_{0.05} = 2.074$$

| | | |
|---|---|---|
| $\mu_1 - \mu_2 = 10.43 \pm 32.54 \sqrt{\frac{1}{14} + \frac{1}{10}} = 10.43 \pm 13.47$ | | NS |

NS = Not significant at the 95% confidence level.

### 3.4.4 Temperature effect

Rudd and Hamilton (1972) found in a model-scaled aerated sewage lagoon that temperatures of 0.5, 5 and 15°C resulted in NTA removal of 25, 47 and 93%, respectively. The NTA input concentration was maintained at 14.0 mg/L. Eden et al (1972) varied the temperature of a laboratory unit containing detergent-free sewage with 5 mg/L NTA from 5 to 20°C and finally to 7.5°C. The corresponding NTA removals were 3, 98 and 82%. Bouveng et al (1968) concluded from a pilot plant study with synthetic sewage that degradation of NTA is more efficient at 20°C than 5°C.

Statistical analysis of the Waterdown data presented in Table 17 shows that there is a significant difference between NTA removal efficiencies at different temperatures. At NTA concentrations of approximately 2.5 mg/L, it is observed that a significant difference in NTA removal exists between 15.5 and 9.4°C. At the high NTA concentrations of about 20 mg/L, there was a very significant difference in NTA removal between 10.3 and 14.5°C. The results show that NTA degradation is significantly affected by wastewater temperature. The magnitude of the temperature effect increases with increased NTA loadings to the treatment plant.

26

<p style="text-align:center">TABLE 17. EFFECT OF TEMPERATURE ON NTA REMOVAL</p>

| | Average Temp °C | Average NTA Level mg/L $H_3NTA$ | n | $\bar{x}$ Average % NTA Removal | $\Sigma(x_i-\bar{x})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|
| $\mu_1$ | 15.5 | 2.3 | 7 | 98.55 | 11.92 | 1.4 |
| $\mu_2$ | 9.8 | 2.6 | 14 | 85.29 | 1 524.95 | 10.8 |
| $\mu_3$ | 9.4 | 2.7 | 17 | 88.29 | 2 798.26 | 13.2 |
| | | | 38 | | 4 335.13 | |

$$S_p^2 = \frac{4\,335.13}{35} \qquad S_p = 11.13 \qquad t_{0.05} = 2.03$$

$$\mu_1 - \mu_2 = 13.26 \pm 22.59\sqrt{\tfrac{1}{7} + \tfrac{1}{14}} = 13.26 \pm 10.46 \quad S$$

$$\mu_1 - \mu_3 = 10.26 \pm 22.59\sqrt{\tfrac{1}{7} + \tfrac{1}{17}} = 10.26 \pm 10.14 \quad S$$

$$\mu_2 - \mu_3 = 3.0 \pm 22.59\sqrt{\tfrac{1}{14} + \tfrac{1}{17}} = -3.0 \pm 8.15 \quad NS$$

| | Average Temp °C | Average NTA Level mg/L $H_3NTA$ | n | $\bar{x}$ Average % NTA Removal | $\Sigma(x_i-\bar{x})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|
| $\mu_1$ | 10.3 | 21.9 | 13 | 58.29 | 970.31 | 9.0 |
| $\mu_2$ | 14.5 | 19.2 | 10 | 89.36 | 2 387.44 | 16.3 |
| | | | 23 | | 3 357.75 | |

$$S_p^2 = \frac{3\,357.75}{21} \qquad S_p = 12.35 \qquad t_{0.05} = 2.074$$

$$\mu_1 - \mu_2 = 31.07 \pm 25.61\sqrt{\tfrac{1}{13} + \tfrac{1}{10}} = 31.07 \pm 10.77 \quad S$$

NS = Not significant at the 95% confidence level.
S = Significant at the 95% confidence level.

## 3.4.5 Effect of NTA loading

In a study of NTA removal at a 1 362 m³/d (0.3 MIGD) sewage treatment plant (Shumate et al, 1970), it was found that NTA removal was 89.4, 90.0 and 75.2% for nominal NTA dosages of 2, 8 and 16 mg/L, respectively. No adverse effect on the treatment plant due to the NTA additions was observed. The Gloucester study (Shannon and Kamp, 1973) reported NTA removal of 73 and 61% at average NTA loadings of 0.7 and 2.2 mg/L, respectively.

Data from the alum addition period and Phase 2 (2nd trial) of this study were selected for analysis of the effect of NTA loading on its removal because the temperature variations in each period were minimal. Table 18 shows that there is a significant difference in NTA removal between high and low NTA spiking levels. Thompson and Duthie (1968) observed that the rate of NTA removal was in all cases a zero order reaction. If the data obtained in this study at 9 to 10°C is lumped and evaluated, pseudo first order kinetics for NTA removal are

<p style="text-align:center">27</p>

suggested. Sufficient data is not available to repeat the analysis in the higher temperature rate. Pseudo first order kinetics, however, are not uncommon in waste treatment systems treating mixed wastes.

TABLE 18. EFFECT OF NTA LOADING ON ITS REMOVAL

| | Average NTA Level mg/L H₃NTA | Average Temp °C | n | $\bar{X}$ Average % NTA Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|
| $\mu_1$ | 2.7 | 9.4 | 17 | 88.29 | 2 798.26 | 13.2 |
| $\mu_2$ | 14.5 | 9.2 | 16 | 64.75 | 1 303.12 | 9.3 |
| | | | 33 | | 4 101.38 | |

$$S_p^2 = \frac{4\ 101.38}{31} \qquad S_p = 11.50 \qquad t_{0.05} = 2.042$$

$$\mu_1 - \mu_2 = 23.54 \pm 23.49\sqrt{\frac{1}{17} + \frac{1}{16}} = 23.54 \pm 8.18 \quad S$$

| | Average NTA Level mg/L H₃NTA | Average Temp °C | n | $\bar{X}$ Average % NTA Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
|---|---|---|---|---|---|---|
| $\mu_1$ | 2.6 | 9.8 | 14 | 85.29 | 1 524.95 | 10.8 |
| $\mu_2$ | 7.5 | 10.2 | 13 | 47.96 | 2 239.19 | 13.7 |
| | | | 27 | | 3 764.14 | |

$$S_p^2 = \frac{3\ 764.14}{25} \qquad S_p = 12.27 \qquad t_{0.05} = 2.06$$

$$\mu_1 - \mu_2 = 37.33 \pm 25.28\sqrt{\frac{1}{14} + \frac{1}{13}} = 37.33 \pm 9.74 \quad S$$

S = Significant at the 95% confidence level.

## 3.5 Transport of Heavy Metals from Treatment Plant

### 3.5.1 General

Nitrilotriacetic acid is a strong chelating agent. Its anions can form complexes with metallic cations. From the environmental protection point of view, there is serious concern as to the formation of NTA-metal complexes and their subsequent degree of biodegradation in wastewater treatment plants. If the NTA-metal complexes are not readily degraded in the plant, there will be transport through, or washout of, heavy metals from the treatment plant to the receiving streams. Shannon et al (1978) studied the biodegradation of various NTA-metal complexes and concluded that for most complexes in the concentrations that might occur, metal transport, even at low winter temperatures, is a problem of little practical significance. In the Waterdown study, the net effect of chelate formation and their biodegradation was assessed indirectly by comparing the heavy metal removal efficiencies for periods of different NTA dosages. A reduced heavy metal removal efficiency in the presence of NTA would be indicative of heavy metal transport.

### 3.5.2    Heavy metal removal and NTA degradation

In a study by Chau and Shiomi (1972), heavy metals such as Cu, Zn, Fe and Ni, were released from Lake Ontario sediment samples in the form of soluble NTA-metal complexes after NTA was added.  It was found that once the degradation of the added NTA was completed, the concentrations of the soluble or released metals decreased drastically. Chau and Shiomi (1972) suggested that when the NTA complexing mechanism was destroyed through NTA degradation, all the released metals either recombined with their original anions to form precipitants, or were adsorbed by the sediment.  Figure 9 shows the relationship between heavy metal removal efficiencies and percent NTA removal in this study.  The heavy metals examined included Zn, Cu, Fe and Al.  Except for Cu, the general trend indicates that higher NTA removal generally results in higher heavy metal removal.  This is to be expected since a higher NTA removal efficiency means less NTA available to form chelates with the heavy metals.  Furthermore, the overall NTA removal may also include the biodegradation of the NTA portion of a NTA-metal complex.

### 3.5.3    Effect of chemical addition

At relatively constant temperature and NTA loading, the addition of $FeCl_3$ to the treatment plant was found to improve the removal efficiencies for Zn, Cu and Al by approximately 25%.  The results are statistically significant as shown in Table 19.  The amount of complexing or solubilization of the heavy metals by NTA may have been reduced as a result of $FeCl_3$ addition.  The iron would compete with the other heavy metals for NTA's chelating capacity with the result that a lesser amount of the other heavy metals are solubilized (Ashforth and Calvin, 1973).

The heavy metal data during the alum addition period was erratic.  The main cause of the variation may have been the start-up difficulties.  Solids carryover was also observed.  As a result, the effect of alum addition could not be assessed.
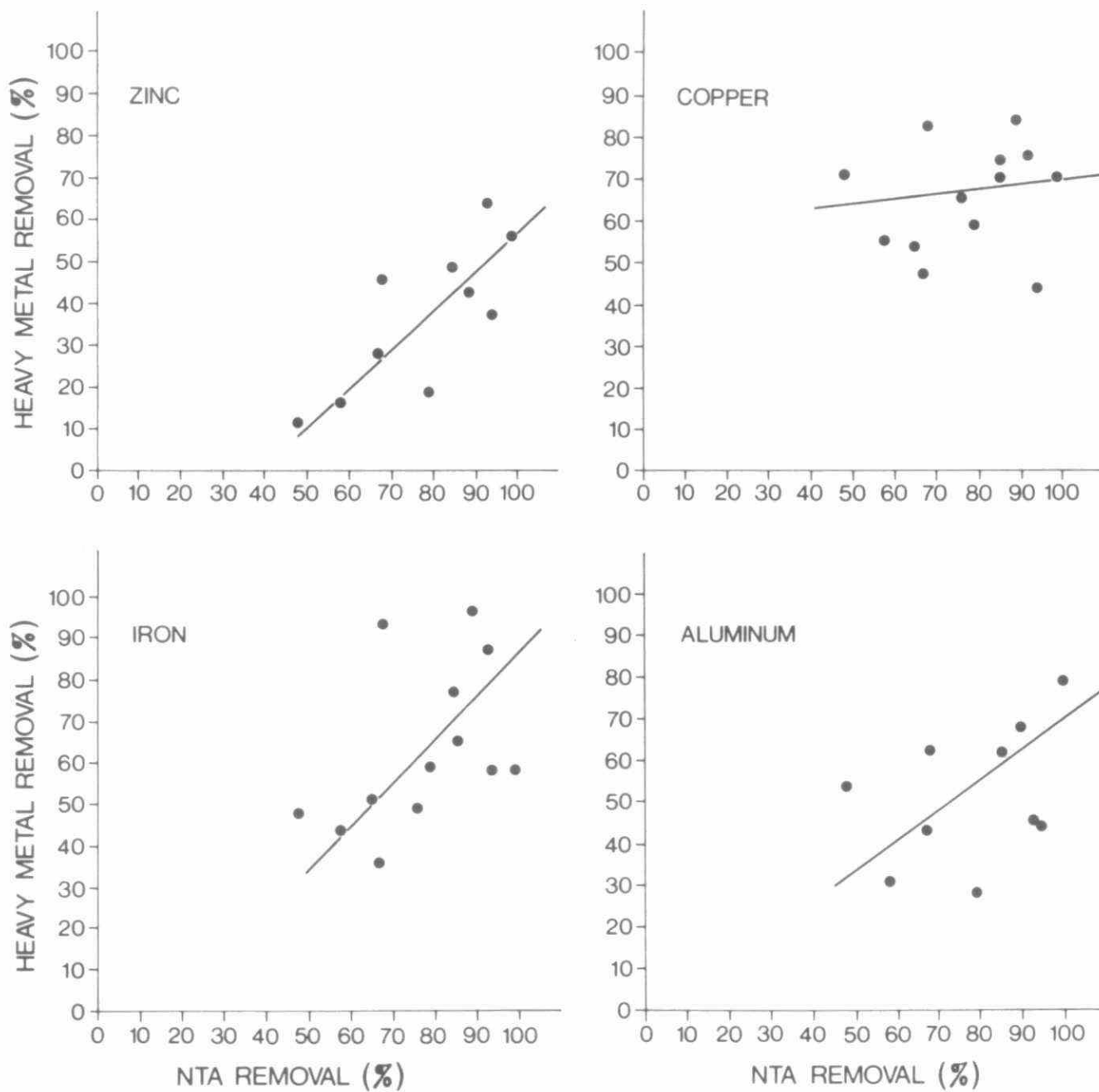
FIGURE 9. HEAVY METAL REMOVAL AS A FUNCTION OF NTA REMOVAL

TABLE 19.  EFFECT OF $FeCl_3$ ADDITION ON HEAVY METAL REMOVAL IN THE PRESENCE OF NTA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Zinc Removal** | | | | |
| | Precipitant | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % Heavy Metal Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
| $\mu_1$ | With $FeCl_3$ | 10.8 | 12.0 | 7 | 45.7 | 1 594.15 | 16.3 |
| $\mu_2$ | No $FeCl_3$ | 9.5 | 11.9 | 12 | 19.3 | 1 377.55 | 11.2 |
| | | | | 19 | | 2 971.70 | |
| | $S_p^2 = \dfrac{2\ 971.70}{17}$ | | | | $S_p = 13.22$ | $t_{0.05} = 2.110$ | |
| | $\mu_1 - \mu_2 = 26.4 \pm 27.89\sqrt{\dfrac{1}{7}+\dfrac{1}{12}} = 26.4 \pm 13.27$ | | | | | | S |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Copper Removal** | | | | |
| | Precipitant | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % Heavy Metal Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
| $\mu_1$ | With $FeCl_3$ | 10.8 | 12.0 | 9 | 82.06 | 426.08 | 7.3 |
| $\mu_2$ | No $FeCl_3$ | 9.5 | 11.9 | 14 | 58.70 | 5 051.87 | 19.7 |
| | | | | 23 | | 5 477.95 | |
| | $S_p^2 = \dfrac{5\ 477.95}{21}$ | | | | $S_p = 16.15$ | $t_{0.05} = 2.08$ | |
| | $\mu_1 - \mu_2 = 23.36 \pm 33.59\sqrt{\dfrac{1}{9}+\dfrac{1}{14}} = 23.36 \pm 14.35$ | | | | | | S |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Aluminum Removal** | | | | |
| | Precipitant | Average NTA Level mg/L $H_3NTA$ | Average Temp °C | n | $\bar{X}$ Average % Heavy Metal Removal | $\Sigma(X_i-\bar{X})^2$ | Standard Deviation |
| $\mu_1$ | With $FeCl_3$ | 10.8 | 12.0 | 7 | 62.6 | 5 426.03 | 30.0 |
| $\mu_2$ | No $FeCl_3$ | 9.5 | 11.9 | 12 | 28.8 | 4 716.50 | 20.7 |
| | | | | 19 | | 10 142.53 | |
| | $S_p^2 = \dfrac{10\ 142.53}{17}$ | | | | $S_p = 24.43$ | $t_{0.05} = 2.11$ | |
| | $\mu_1 - \mu_2 = 33.8 \pm 51.54\sqrt{\dfrac{1}{7}+\dfrac{1}{12}} = 33.8 \pm 24.51$ | | | | | | S |

S = Significant at the 95% confidence level.

## 3.5.4    Effect of NTA loading

Nilsson (1971) added heavy metals and NTA to wastewater
samples and found that Cu and Pb escaped precipitation in the presence
of NTA ranging in concentrations from 0 to 12 mg/L.  Sanchez and Lee
(1973) added NTA to dredged lake sediment samples and reported that
increasing amounts of Fe and Mg were solubilized due to an increase in
NTA concentrations.  However, contrary to what would be expected, the
copper released from the sediments was found to decrease with increasing
NTA.  Shannon and Kamp (1973) reported no transport of Fe, Cu, Zn and
Pb due to NTA increase.  This could be due to the relatively low average
NTA dosage used in their study, but there was some evidence of transport
of Ni and Cd.  The average fraction of metal transported through a full
scale waste treatment plant and a pilot plant spiked with NTA operating
in parallel, was examined by Cleasby et al (1974).  Statistical analysis
of the data revealed no significant difference in metal transport
between the two plants and no correlation between NTA loading and metal
transport.  Renn (1974), who examined a small package plant, found that
zinc and iron transport increased with increased NTA loading.  To
evaluate the effect of different NTA effluent levels on heavy metal
removal, data from three study periods (iron addition period, second
year Phase I and Phase II) were analyzed for significant differences
in metal removal.  For the metals considered (Al, Zn, Cu, Fe,
Ni and Pb) no general trend in heavy metal removal efficiency is
evident (Table 20).  The removal of aluminum, nickel and lead is in-
dependent of NTA concentration.  Zinc and iron removal tend to decrease
with increasing NTA level, however, in most cases the differences in
removal are not statistically significant.  For copper and iron
removal, the trend is for increased copper and iron removal with
increased NTA level in the effluent.  However, as with zinc, the
differences in removal are, in most instances, not statistically
significant.  Aluminum, Ni and Pb removal did not increase with increased
NTA level in the effluent.  The data, in general, tend to confirm the
results obtained by Cleasby et al (1974).  That is:  zinc transport
increased with increased NTA level in the effluent.

32

## TABLE 20. EFFECT OF NTA LOADING ON HEAVY METAL REMOVAL

| | NTA Conc. mg/L | Percent Metal Removal | | | | | |
|---|---|---|---|---|---|---|---|
| | | Al | Zn | Cu | Fe | Ni | Pb |
| $\mu_1$ | 0.1 | 79.5 | 55.6 | 69.9 | 58.5 | 43.5 | 75.1 |
| $\mu_2$ | 0.1 | 46.2 | 64.5 | 75.3 | 86.6 | 38.7 | 71.8 |
| $\mu_3$ | 2.0 | 69.1 | 42.9 | 83.7 | 95.7 | 19.6 | 81.7 |
| $\mu_4$ | 3.5 | 62.6 | 45.7 | 82.1 | 93.3 | 38.0 | 75.8 |
| $\mu_1 - \mu_2$ | | NS | NS | NS | S | NS | NS |
| $\mu_1 - \mu_3$ | | NS | NS | S | S | S | NS |
| $\mu_1 - \mu_4$ | | NS | NS | S | S | NS | NS |
| $\mu_2 - \mu_3$ | | NS | S | S | NS | NS | NS |
| $\mu_2 - \mu_4$ | | NS | S | S | NS | NS | NS |
| $\mu_3 - \mu_4$ | | NS | NS | NS | NS | NS | NS |
| $\mu_1$ | 0.7 | 43.8 | 28.1 | 47.3 | 36.2 | | |
| $\mu_2$ | 2.0 | 28.8 | 19.3 | 58.7 | 58.9 | | |
| $\mu_3$ | 9.1 | 31.3 | 15.9 | 55.0 | 43.9 | | |
| $\mu_1 - \mu_2$ | | S | NS | S | S | | |
| $\mu_1 - \mu_3$ | | NS | NS | NS | NS | | |
| $\mu_2 - \mu_3$ | | NS | NS | NS | NS | | |
| $\mu_1$ | 0.3 | 62.7 | 48.2 | 70.3 | 75.9 | | |
| $\mu_2$ | 0.6 | 45.2 | 36.4 | 43.6 | 58.2 | | |
| $\mu_3$ | 3.9 | 53.7 | 11.4 | 71.4 | 47.9 | | |
| $\mu_1 - \mu_2$ | | S | NS | S | S | | |
| $\mu_1 - \mu_3$ | | NS | S | NS | S | | |
| $\mu_2 - \mu_3$ | | NS | S | S | NS | | |

NS = Not significant at the 95% confidence level.
S = Significant at the 95% confidence level.

REFERENCES

Ashforth, G.K. and G. Calvin, "Safety Evaluation of Substitutes for Phosphorus in Detergents", Water Research, 7:309, 1973.

Bouveng, H.O., G. Davisson and E. Steinberg, "NTA in Sewage Treatment", Vatten, 4:348, 1968.

Chau, Y.K. and M.T. Shiomi, "Complexing Properties of Nitrilotriacetic Acid in the Lake Environment", Water, Air and Soil Pollution, 1:149, 1972.

Cleasby, J.L., D.W. Hubly, T.A. Ladd and E.A. Schon, "Trickling Filtration of a Waste Containing NTA", Journal Water Pollution Control Federation, 46(8):1873, 1974.

Eden, G.E., G.E. Culley and R.C. Rootham, "Effect of Temperature on the Removal of NTA (Nitrilotriacetic Acid) During Sewage Treatment", Water Research, 6:877, 1972.

Epstein, S.S., "Toxicological and Environmental Implications on the Use of Nitrilotriacetic Acid as a Detergent Builder", International Journal Environmental Studies, 2:291, 1972.

Forsberg, C. and L. Wiberg, "Flocculation of Phosphorus in Domestic Sewage, NTA and Growth of Algae", Vatten, 24:142, 1968.

Gudernatsch, H., "Behaviour of NTA in the Purification Process and in Effluent", Translation from GWF - Wasser/Abwasser, 111:511, 1970.

Nilsson, R., "Removal of Metals by Chemical Treatment of Municipal Waste Water", Water Research, 5:51, 1971.

Prakash, A., "NTA (Nitrilotriacetic Acid) - An Ecological Appraisal", Environmental Protection Service Report, EPS 3-WP-76-8, Water Pollution Control Directorate, Ottawa, 1976.

Renn, C.E., "Biodegradation of NTA Detergents in a Waste Water Treatment System", Journal Water Pollution Control Federation, 46(10):2363, 1974.

Rudd, J.W.M. and R.D. Hamilton, "Biodegradation of Trisodium Nitrilotriacetate in a Model Aerated Sewage Lagoon", Journal Fisheries Research Board Canada, 29:1203, 1972.

Sanchez, I. and G.F. Lee, "Sorption of Copper on Lake Monona Sediments - Effect of NTA on Copper Release from Sediments", Water Research, 7:587, 1973.

Shannon, E.E. and L.J. Kamp, "Detergent Substitution Studies at C.F.S. Gloucester", Environmental Protection Service Report, EPS 4-WP-73-3, Water Pollution Control Directorate, Ottawa, 1973.

Shannon, E.E., P.J.A. Fowlie and R.J. Rush, "A Study of Nitrilotriacetic Acid (NTA) Degradation in a Receiving Stream", Environmental Protection Service Report, EPS 4-WP-74-7, Water Pollution Control Directorate, Ottawa, 1974.

Shannon, E.E., N.W. Schmidtke and B.A. Monaghan, "Activated Sludge Degradation of Nitrilotriacetic Acid (NTA)-Metal Complexes", Environmental Protection Service Report, EPS 4-WP-78-5, Water Pollution Control Directorate, Ottawa, 1978.

Shumate, K.S., J.E. Thompson, J.D. Brookhart and C.L. Dean, "NTA Removal by Activated Sludge Field Study", Journal Water Pollution Control Federation, 42(4):631, 1970.

Standard Methods for the Examination of Water and Wastewater, 13th Edition, American Public Health Association, New York, 1971.

Swisher, R.D., M.M. Crutchfield and D.W. Caldwell, "Biodegradation of Nitrilotriacetate (NTA) in Activated Sludge", Environmental Science and Technology, 1:820, 1967.

Thayer, P.S. and C.J. Kensler, "Current Status of the Environmental and Human Safety of Nitrilotriacetic Acid (NTA)", CRC Critical Reviews in Environmental Control, 375, 1973.

Thom, N.S., "Nitrilotriacetic Acid: A Literature Survey", Water Research, 5:391, 1971.

Thompson, J.E. and J.R. Duthie, "The Biodegradability and Treatability of NTA", Journal Water Pollution Control Federation, 40:306, 1968.

Traversy, W.J., "Methods for Chemical Analysis of Water and Wastewaters", Water Quality Division, Department of the Environment, 1971.

Wannacott, T.H. and R.J. Wannacott, Introductory Statistics, John Wiley & Sons, 1969.

## ACKNOWLEDGEMENTS